Introduction to OTA Testing of MIMO Devices

Authors:

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Abstract

- A method for environmental simulation within a fully anechoic chamber has been developed for testing MIMO and related multi-antenna technologies.
- This presentation describes the method and results using a combination of IEEE 802.11 and 3GPP channel models and a IEEE 802.11 DUT
- This presentation was first made at the WiMax Forum held in October 2009

Outline

- The Meaning of MIMO
- MIMO and the RF Environment
- Implications of OTA Testing
- Designing an OTA Environment Simulator
- Initial Results with ETS-Lindgren/Elektrobit OTA R&D System
- Metrics
- Correlation Evaluation
- Open Questions
- Conclusions

The Meaning of MIMO

- **The term MIMO is often used to represent a range of bandwidth/performance enhancing technologies that rely on multiple antennas in a wireless device.**
- **These can be classified into several categories:**
  - "True" MIMO.
  - SIMO technologies like beam forming and receive diversity.
- **While this discussion will concentrate on downlink MIMO, uplink MIMO/MISO concepts are similar.**

The Meaning of MIMO

- **“True” MIMO uses multiple transmit and receive antennas to increase the total information bandwidth through space-time coding.**
  - Multiple channels of communication share the same frequency bandwidth allocation simultaneously.
- **SIMO technologies use the multiple (receive) antennas to improve single channel performance under edge-of-link (EOL) conditions.**

The Meaning of MIMO

- **Beam forming allows the creation of a stronger gain pattern in the direction of the desired signal while simultaneously rejecting undesired signals from other directions.**
- **Receive diversity uses multiple antennas to overcome channel fades by using additional antenna(s) to capture information that may be missing from a single channel.**
  - Includes simple switching diversity or more complicated techniques like maximal ratio combining or other combinatorial diversity techniques.

MIMO and the RF Environment

- All of these multiple antenna technologies share one thing in common – their performance is a function of the environment in which they're used.
- The device adapts to its environment through embedded algorithms that change its (effective) radiation pattern.
- Traditional TRP and TIS metrics are properties of the mobile device only. They represent the average performance of the device to signals from any direction.

MIMO and the RF Environment

- **Metrics like Near Horizon Partial Radiated Power/Sensitivity terms or Mean Effective Gain apply simple environmental models to fixed pattern data, but the basic behavior of the device does not change.**
- **For MIMO technologies, performance is a function of the system and cannot be restricted to the mobile device.**
- **Individual device performance can only be evaluated/compared *in a given environment*.**
- **This implies the need for *environment simulation*.**

Implications of OTA Testing

- **Channel emulators are commonly used to simulate wireless environments for radio development/testing.**
- **Channel models simulate not only a given environment, but also properties of the base station and mobile device including antenna patterns, antenna separation, and angles of departure/arrival (AOD/AOA).**
- **A primary goal of OTA testing is to determine radio performance of the DUT with the actual antenna patterns, orientation, and spacing.**

Implications of OTA Testing

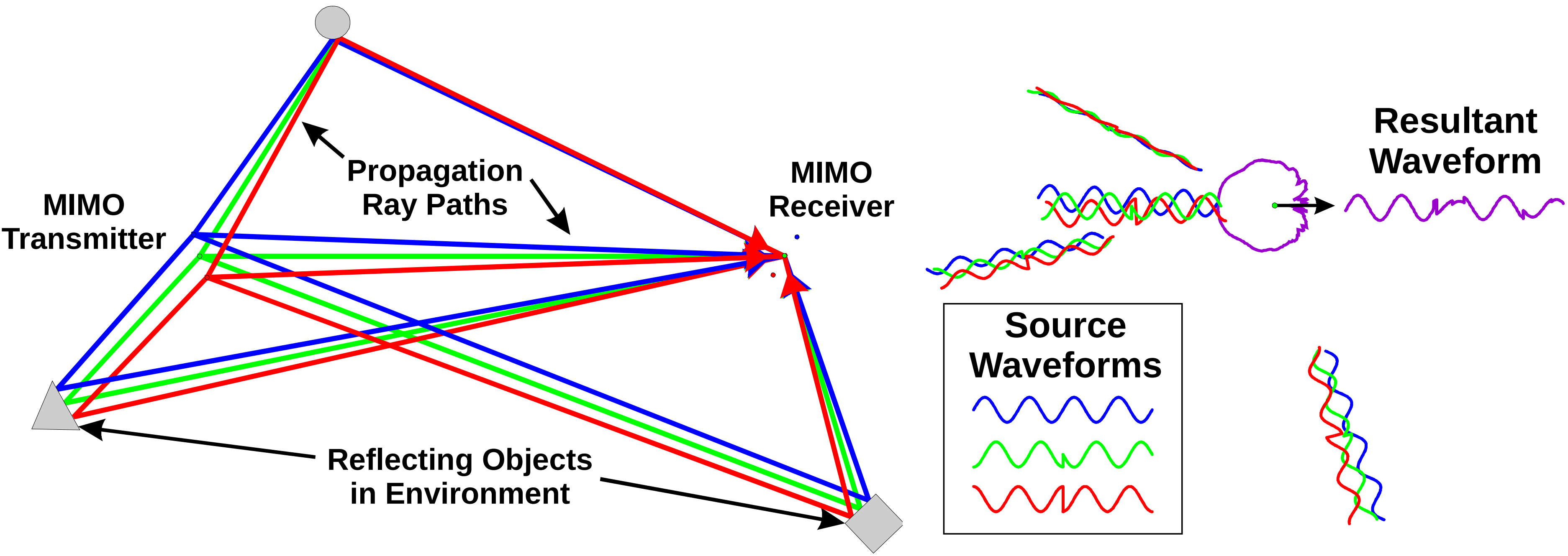
- **If this was all that was required, a combination of antenna pattern measurement and conducted channel modeling would suffice.**
- **However, traditional OTA measurements of TRP/TIS perform simultaneous evaluation of the entire RF signal chain for a variety of reasons:**
  - Platform Desensitization – interference from platform components enters radio through attached antennas.
  - Near Field Influences – including platform structure, head, hands, body, table top, etc.

Implications of OTA Testing

- Mismatch and other Interaction Factors – performance of a radio into a matched 50 Ohm load may not be the same as that into a mismatched or detuned antenna, resulting in non-linear behavior.
- Antenna-Antenna Interactions – mutual coupling of antennas may not be accounted for properly in pattern tests.
- Cable Effects – currents on feed cables can alter the radiation pattern, especially for small DUTs.

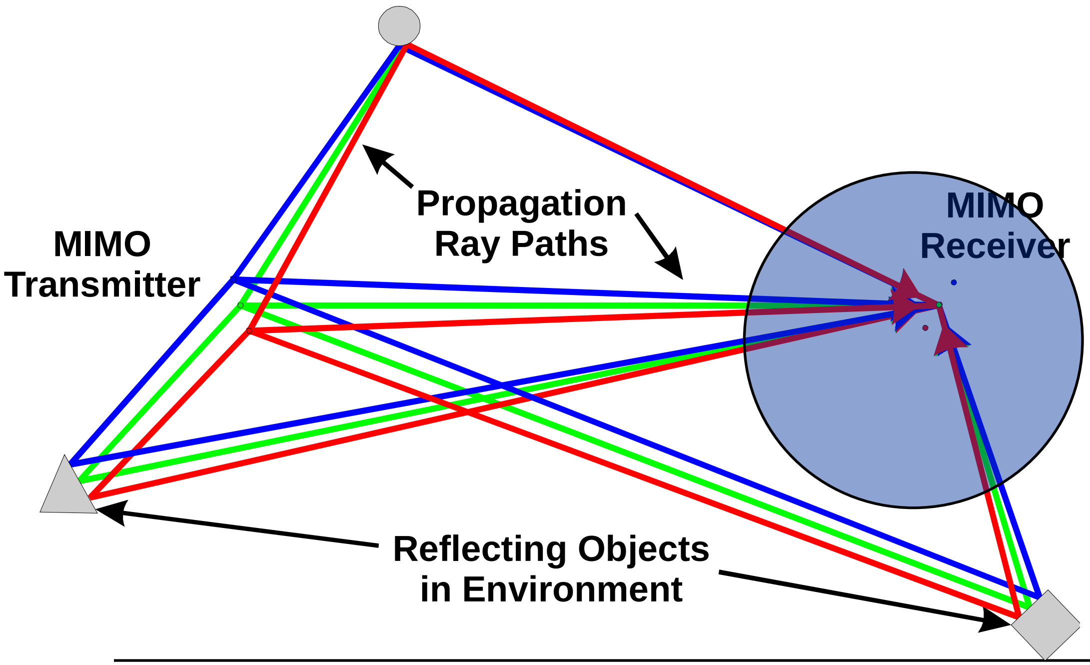
Designing an OTA Environment Simulator

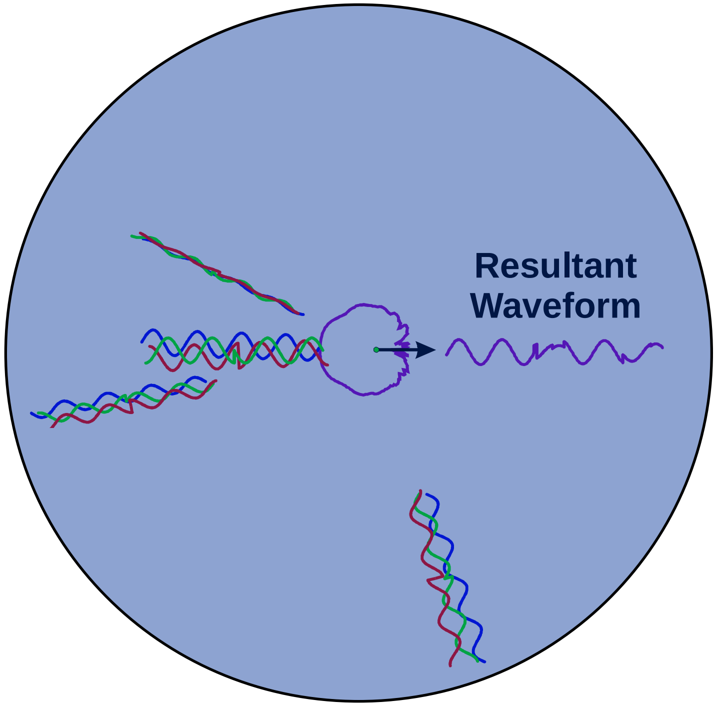
- **MIMO relies on a complex multipath environment to provide the information necessary to reconstruct multiple source signals that have been combined into multiple receive signals.**



Designing an OTA Environment Simulator

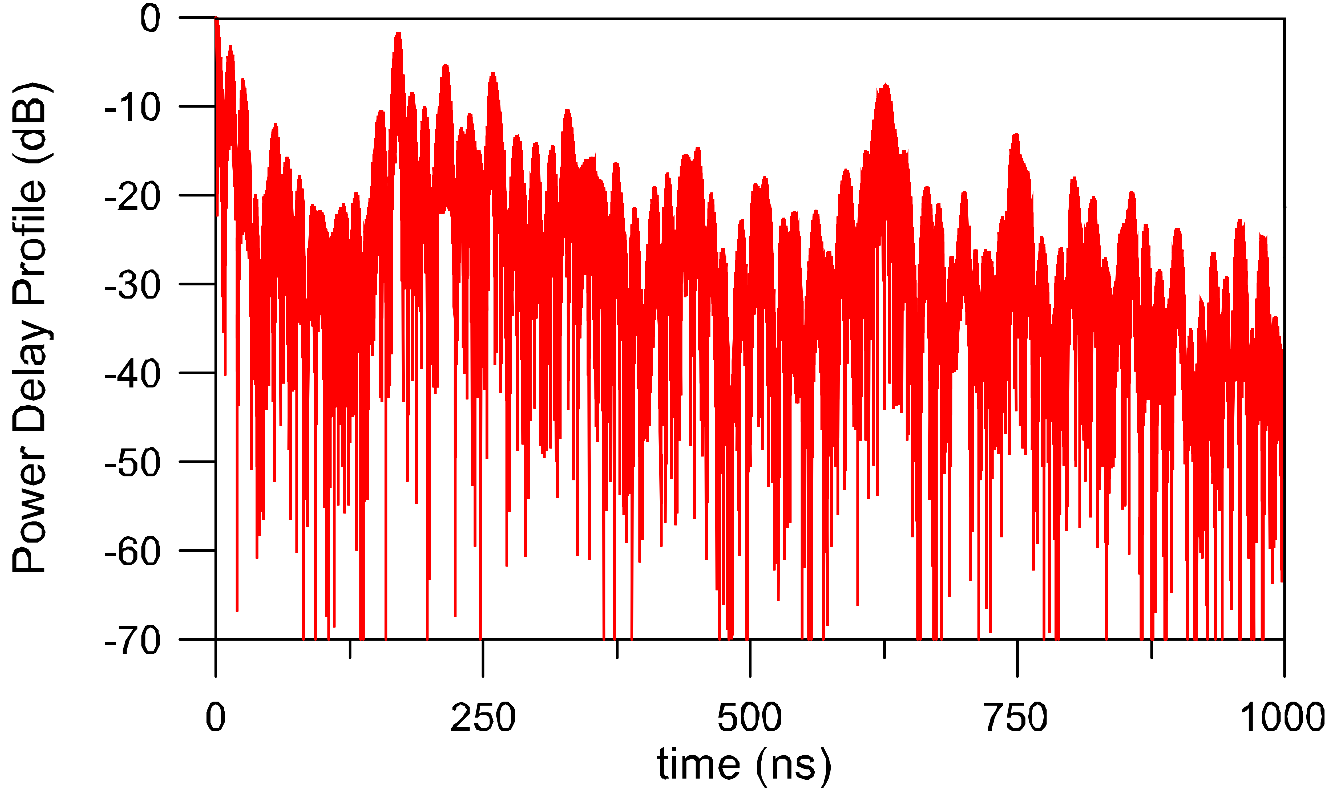
- The goal of the OTA Environment Simulator is to place the DUT in a controlled, isolated near field environment and then simulate everything outside that region.





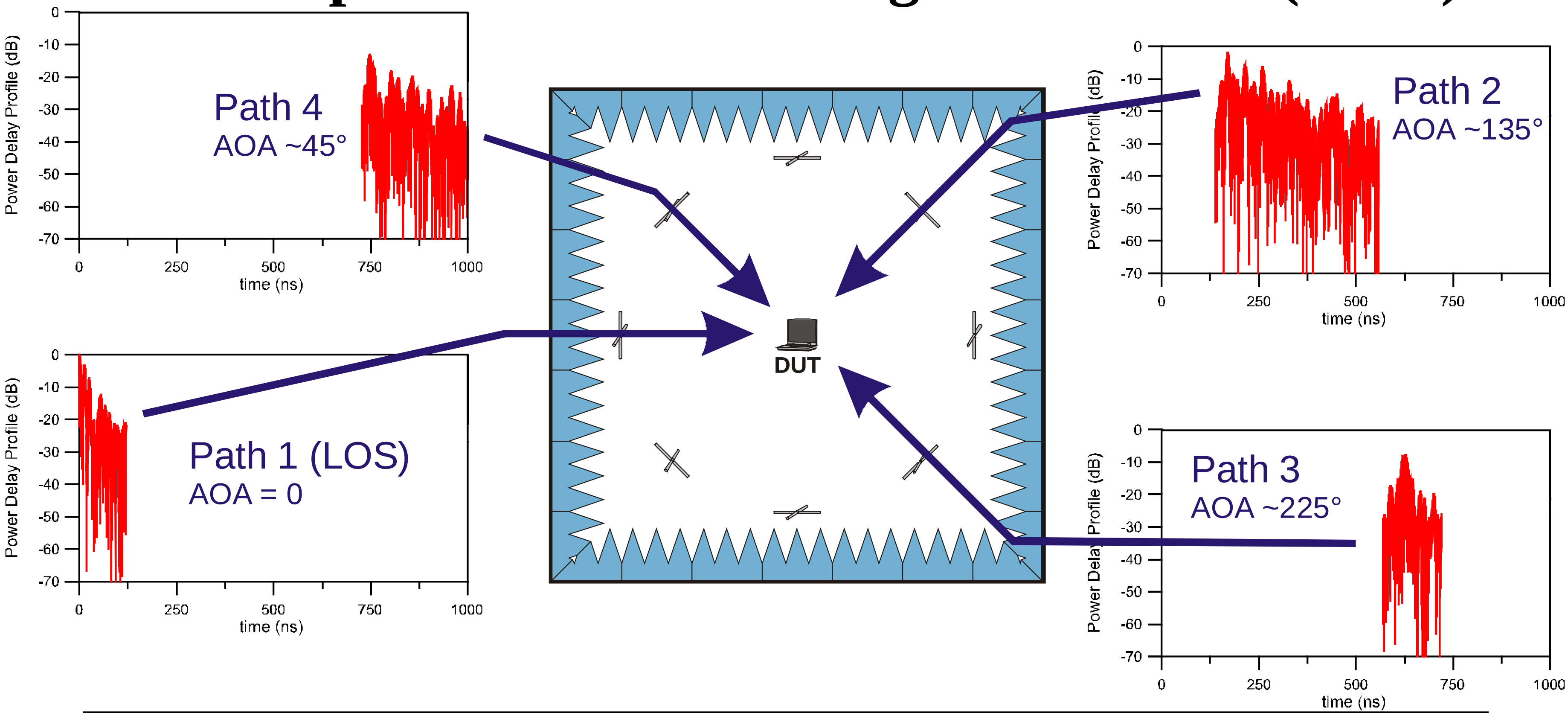
Designing an OTA Environment Simulator

- **Example: Typical Multi-Path Power Delay Profile from a Real World Environment**



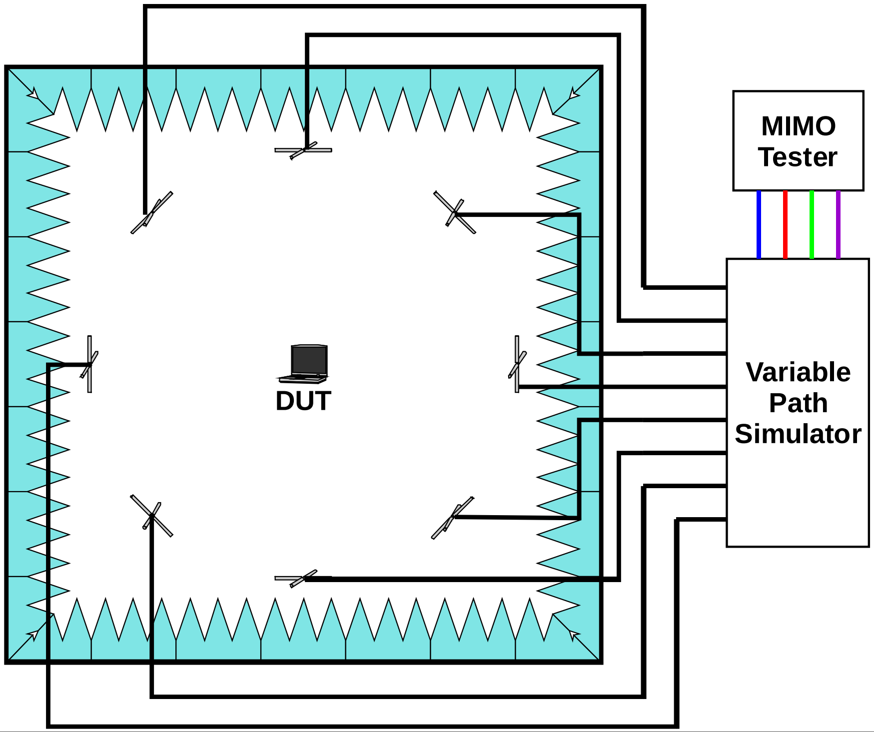
Designing an OTA Environment Simulator

- Using a fully anechoic chamber to isolate the DUT, a matrix of antennas arrayed around the DUT can be used to produce different angles of arrival (AOA)



Designing an OTA Environment Simulator

- **A Variable Path Simulator (ideally a channel emulator with modified channel models) simulates the desired external environment between BSE and DUT.**

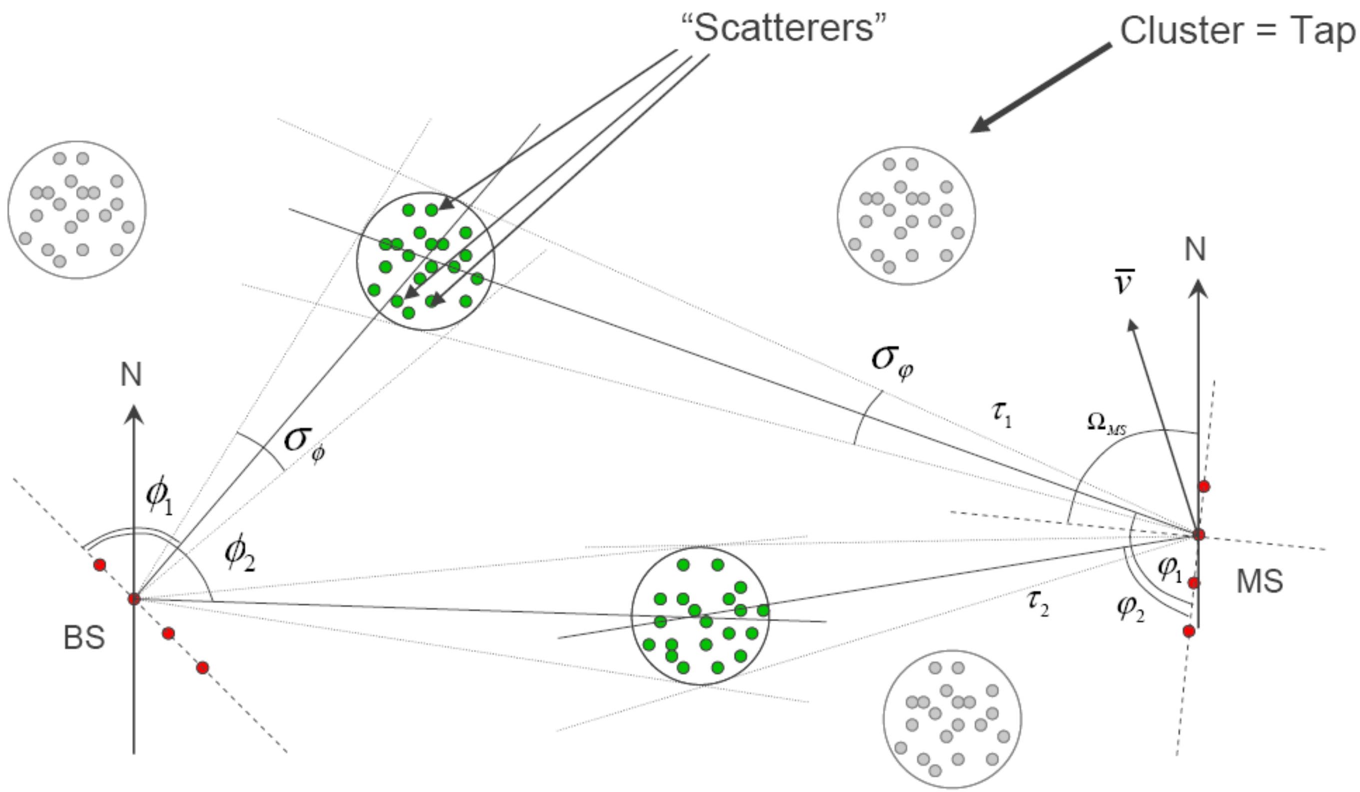


Designing an OTA Environment Simulator

- **Evaluation of SIMO functions like beam forming and receive diversity likely require only rudimentary environment simulation.**
  - Sufficient to simulate only basic directional effects and spatial fading.
- **While there are a variety of simplistic ways to create an external environment containing delay spread, fading, and even repeatable reflection "taps", they may be insufficient for proper evaluation of MIMO performance.**

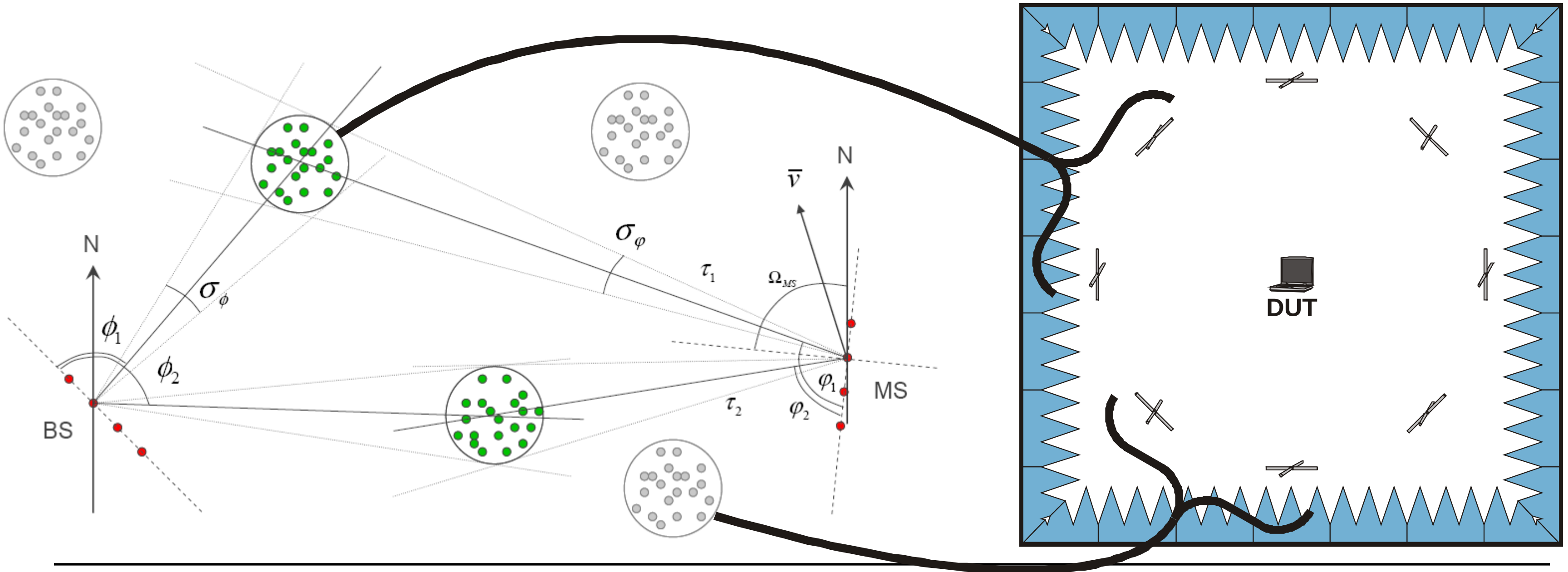
Designing an OTA Environment Simulator

- **MIMO channel models include clusters of scatterers with each tap having an angular spread as well as a delay spread..**



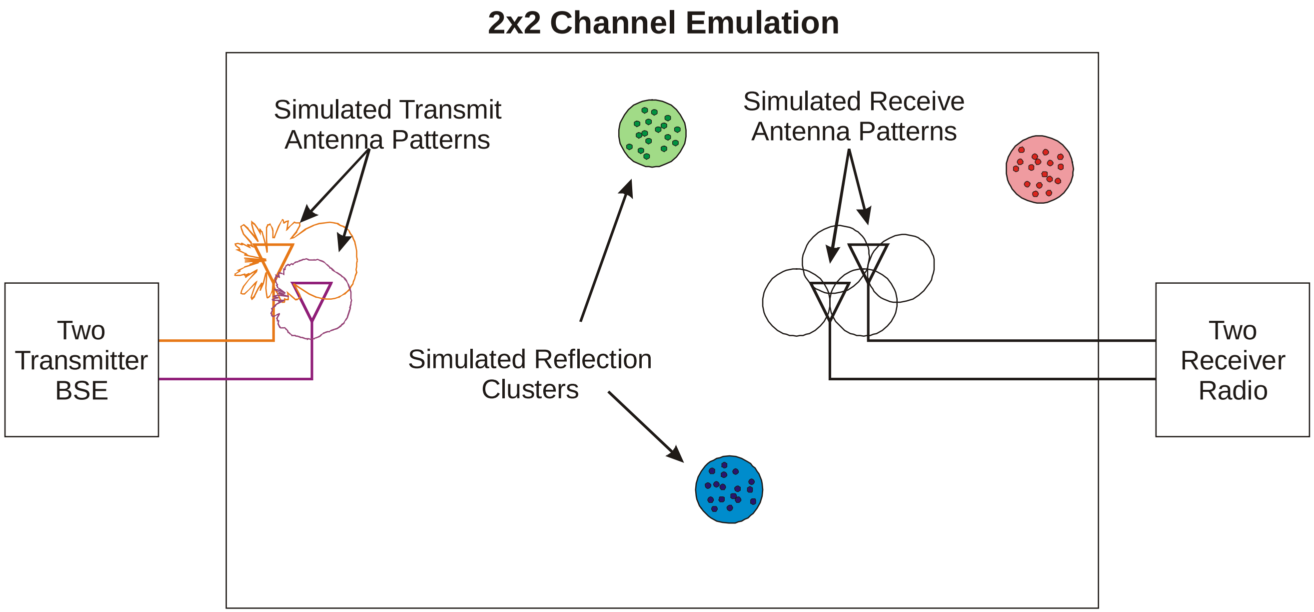
Designing an OTA Environment Simulator

- Simulation of the delay spread would either require an extremely large number of antennas to simulate each scatteror, or the use of an electronic channel emulator to “dither” the signal across multiple antennas to simulate slight variations in AOA.



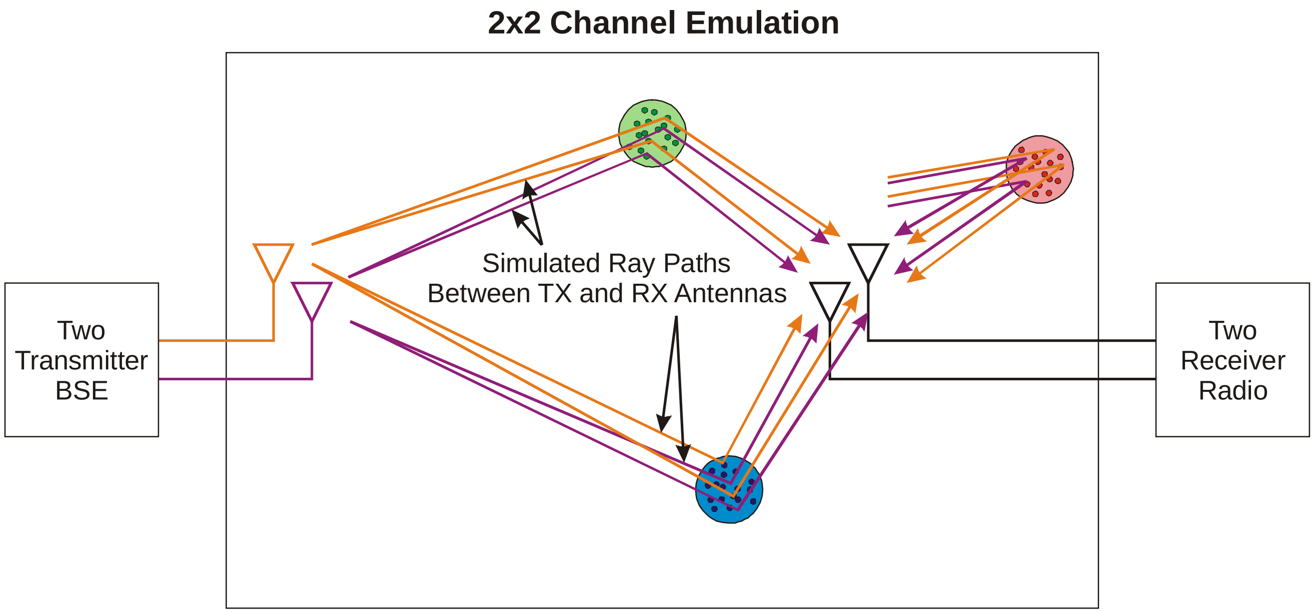
Designing an OTA Environment Simulator

- **Converting a conducted channel model to an OTA channel model:**
  - Conducted model simulates TX and RX antennas.



Designing an OTA Environment Simulator

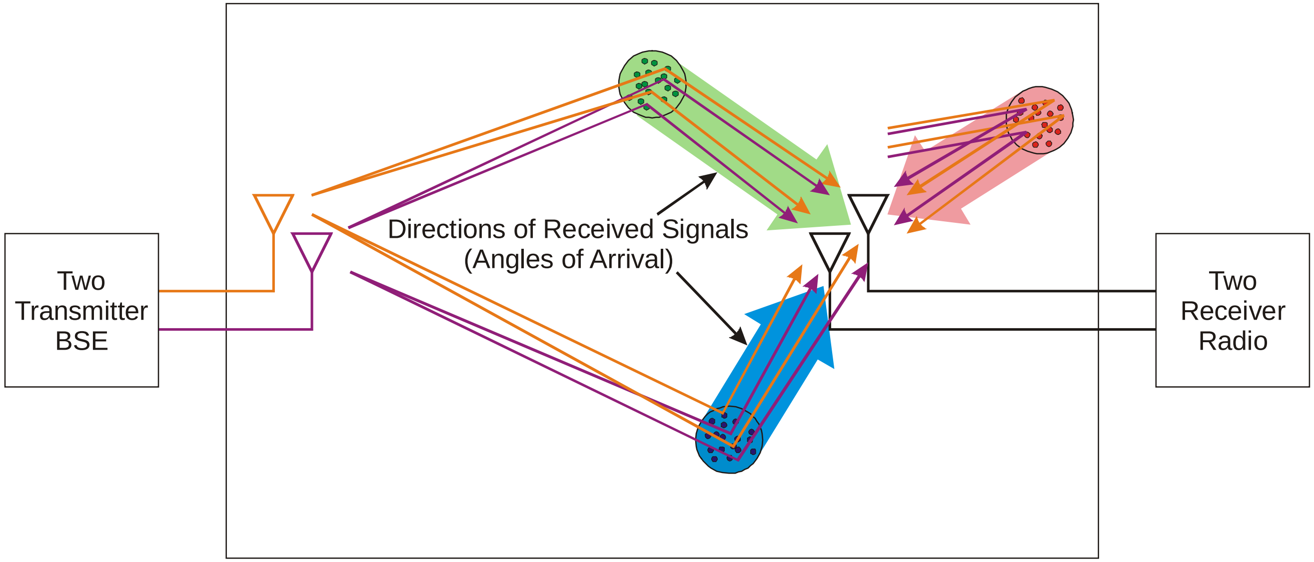
- **Conducted channel model:**
  - Ray paths from reflections in simulated environment are collected at each simulated receive antenna.



Designing an OTA Environment Simulator

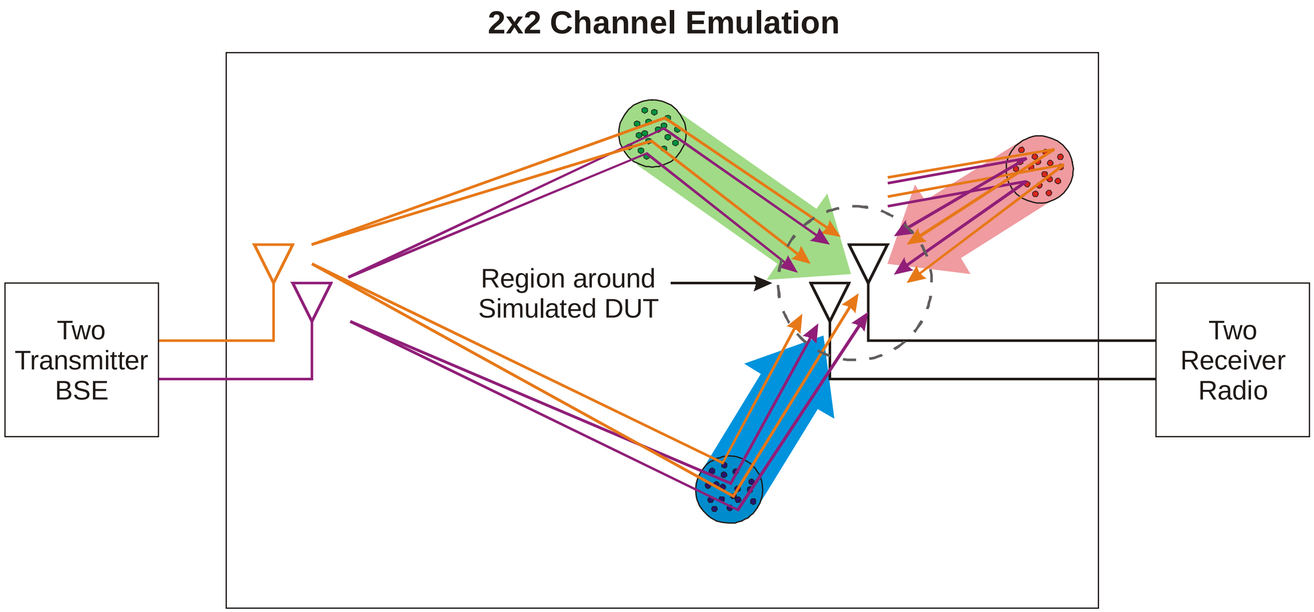
- **Converting a conducted channel model to an OTA channel model:**
  - Clusters produced different angles of arrival (AOA)

2x2 Channel Emulation



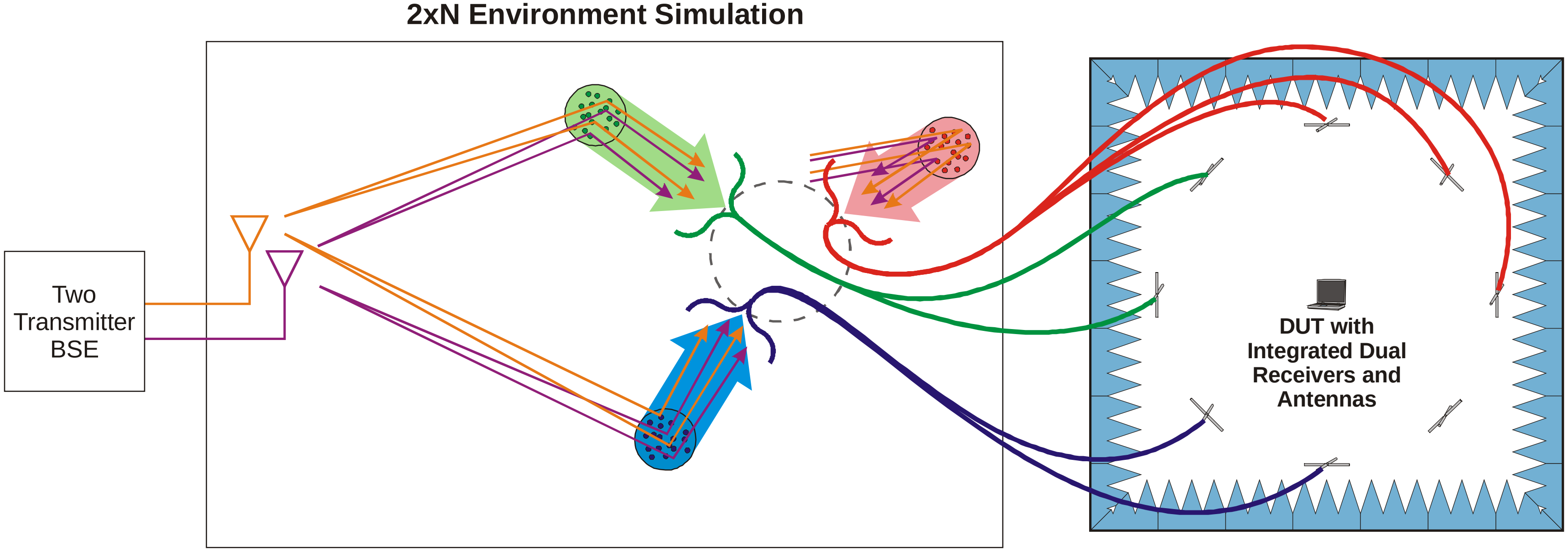
Designing an OTA Environment Simulator

- **Converting a conducted channel model to an OTA channel model:**
  - Grouping AOAs, we can remove virtual RX antennas.



Designing an OTA Environment Simulator

- **OTA channel model:**
  - 2xN channel emulator used to feed N antennas for AOA simulation around DUT with real antennas.

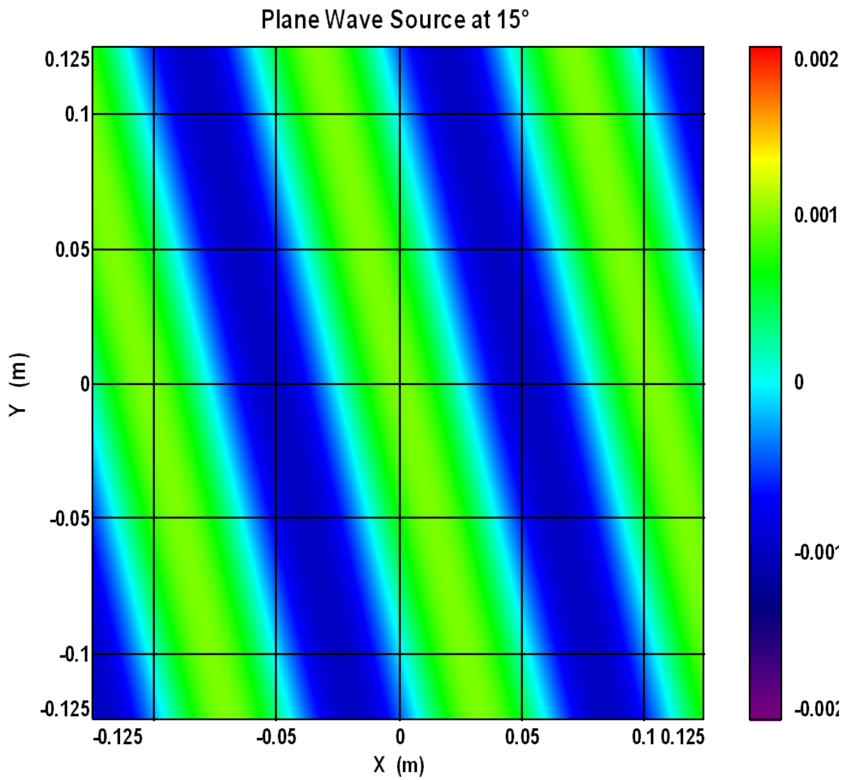


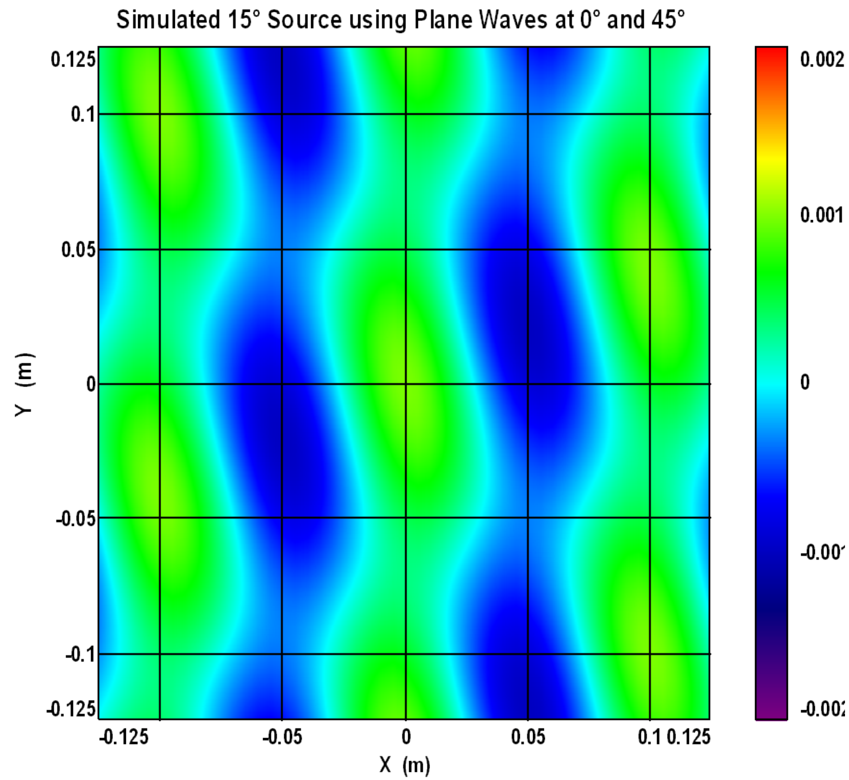
Designing an OTA Environment Simulator

- **Ideally, the sphere around the DUT would define a perfect boundary condition that exactly reproduces the desired field distribution inside the test region.**
- **Practicality and physical limitations impose restrictions that create a less than ideal environment simulation.**
- **The chosen number of antenna positions limits the available range of “Real” propagation directions.**
- **“Dithering” of signals across multiple antennas does not produce true plane wave behavior in test region.**
  - Results in an interference pattern with wave-like distribution in center of test region.

Designing an OTA Environment Simulator

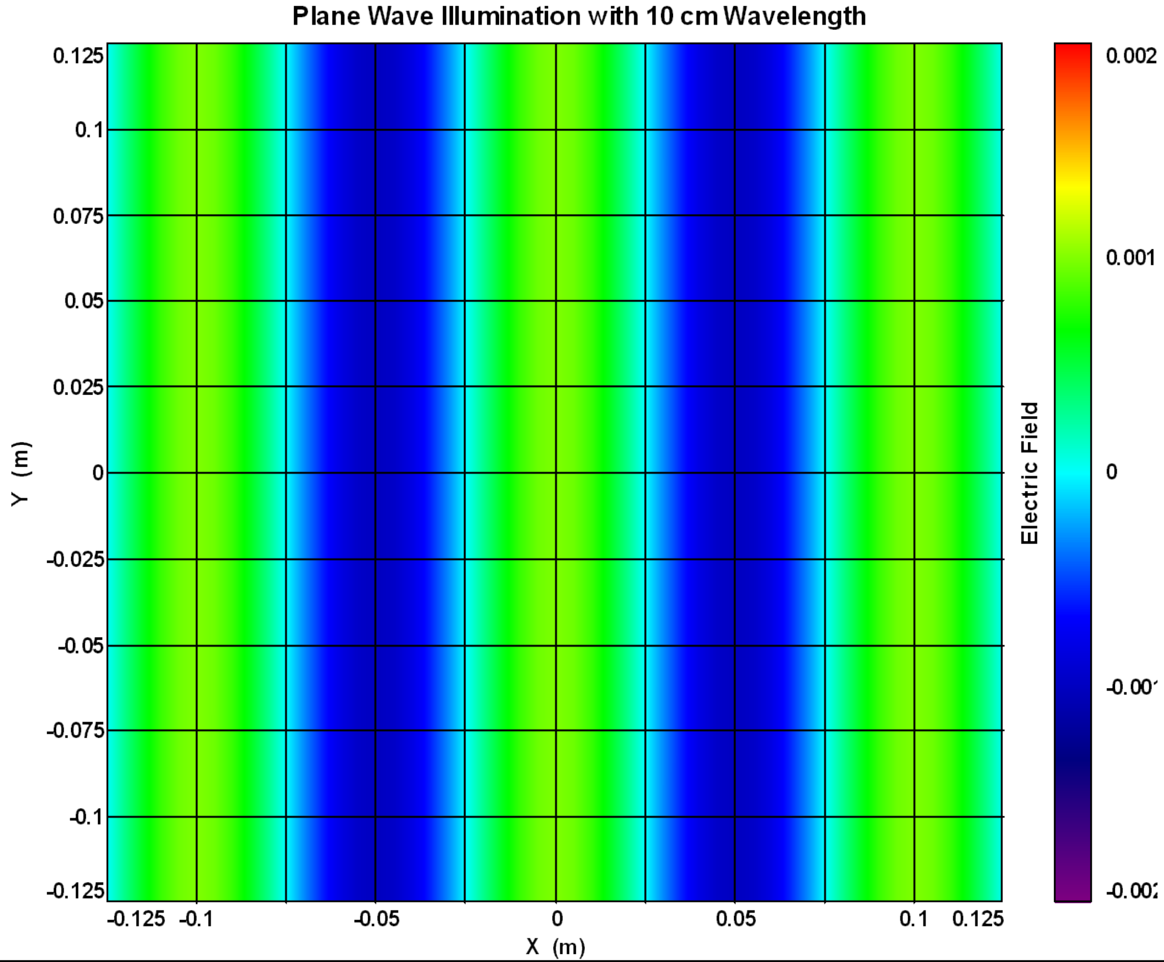
- **"Dithering" results in an interference pattern with wave-like distribution in center of test region.**
  - Quality depends on angular spacing and number of antennas used to create interference pattern.





Designing an OTA Environment Simulator

- **Effect of angular resolution on dithered signals.**



Designing an OTA Environment Simulator

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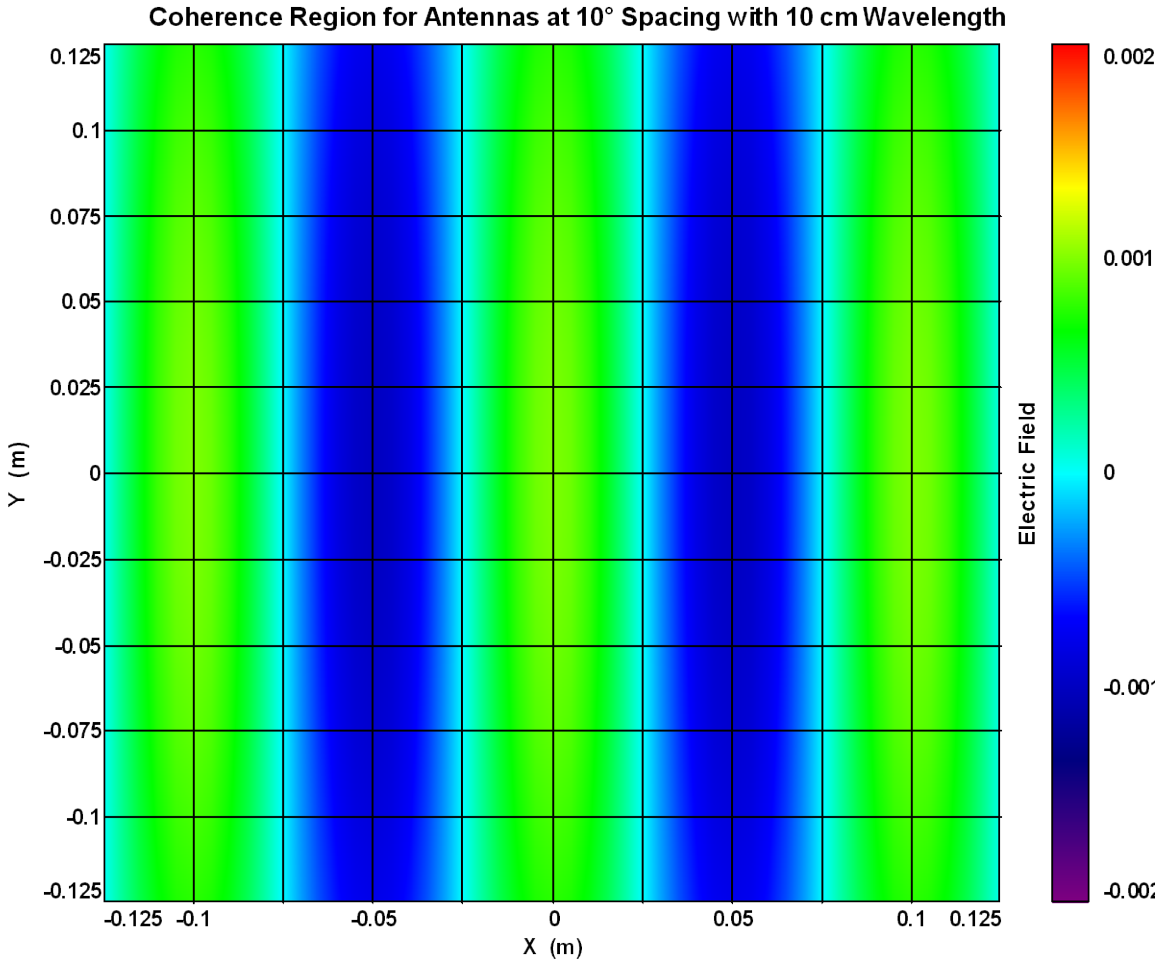

Designing an OTA Environment Simulator

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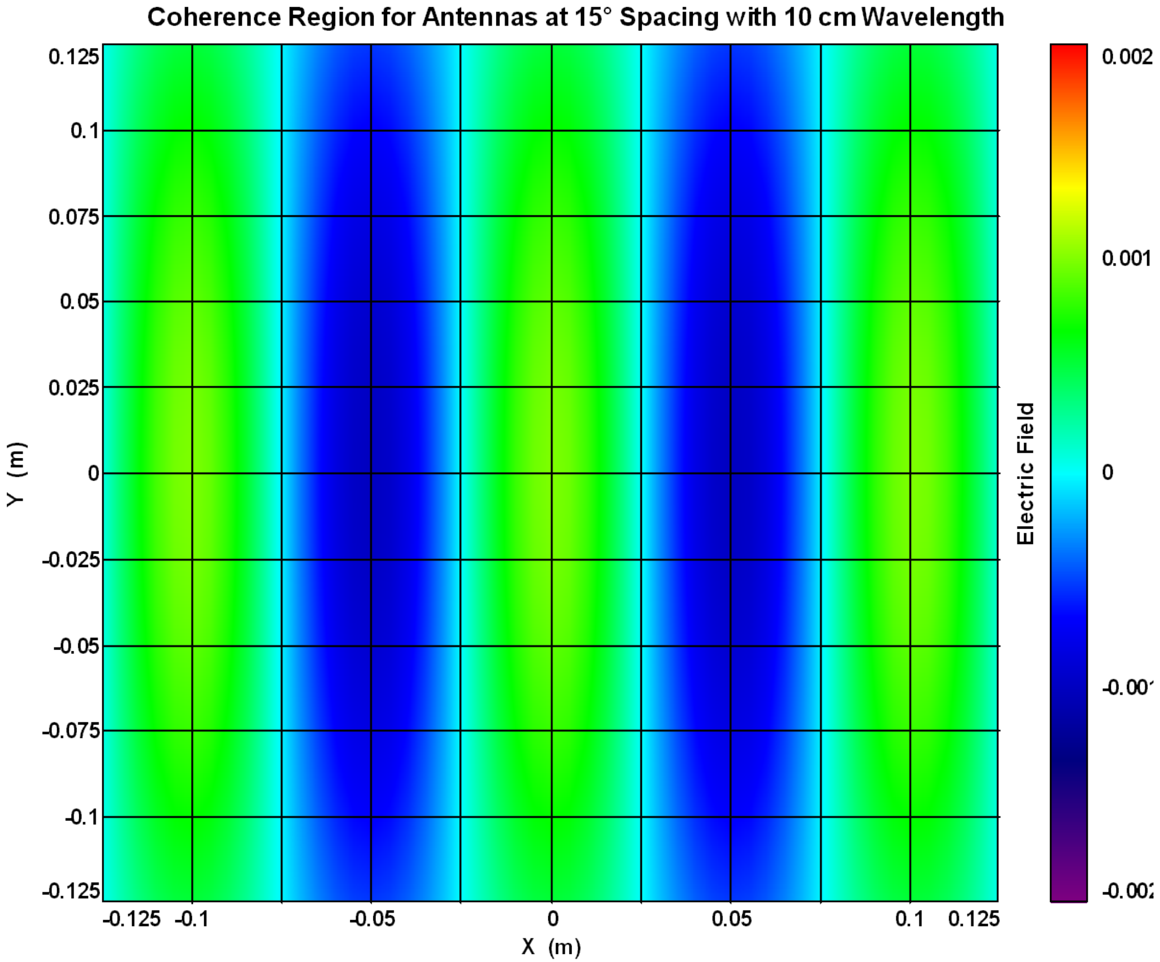

Designing an OTA Environment Simulator

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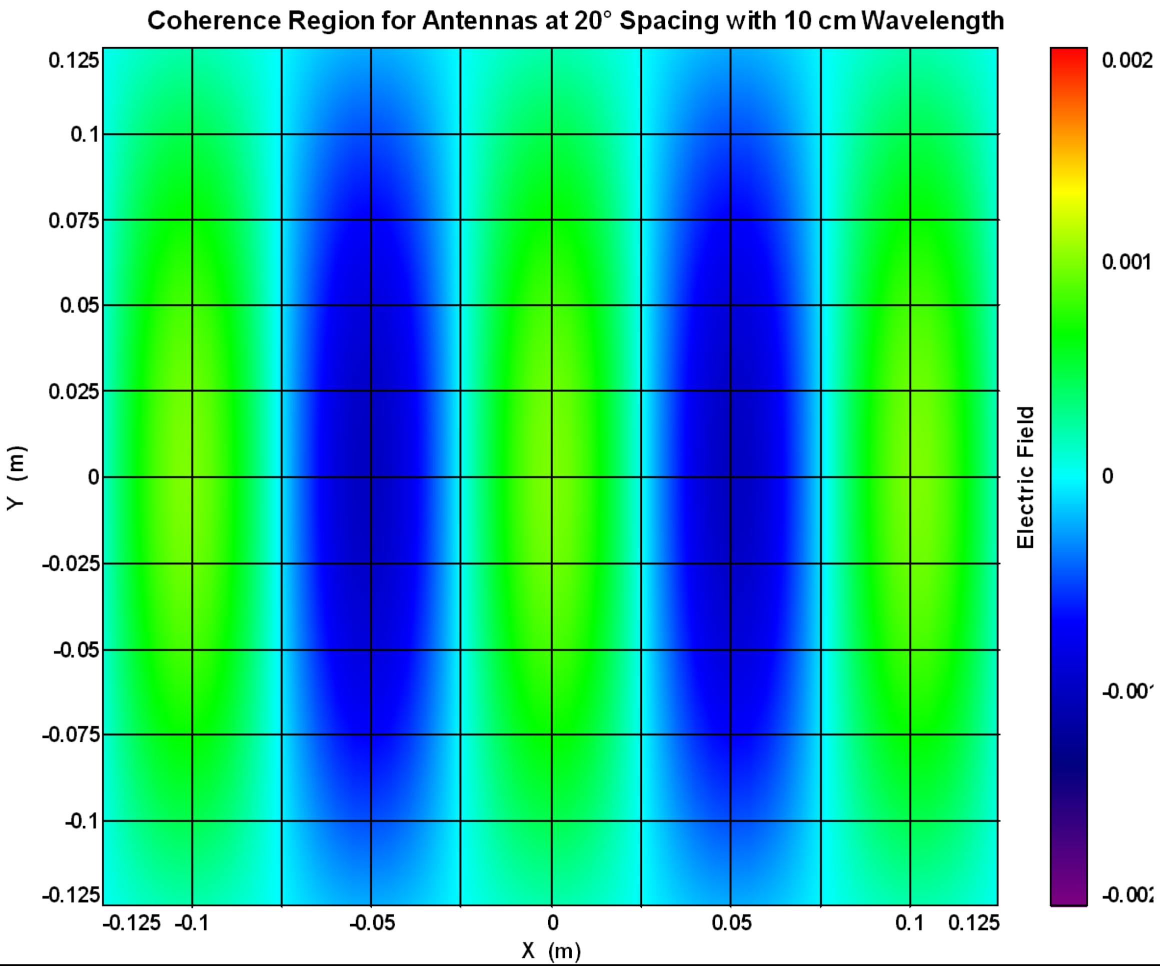

Designing an OTA Environment Simulator

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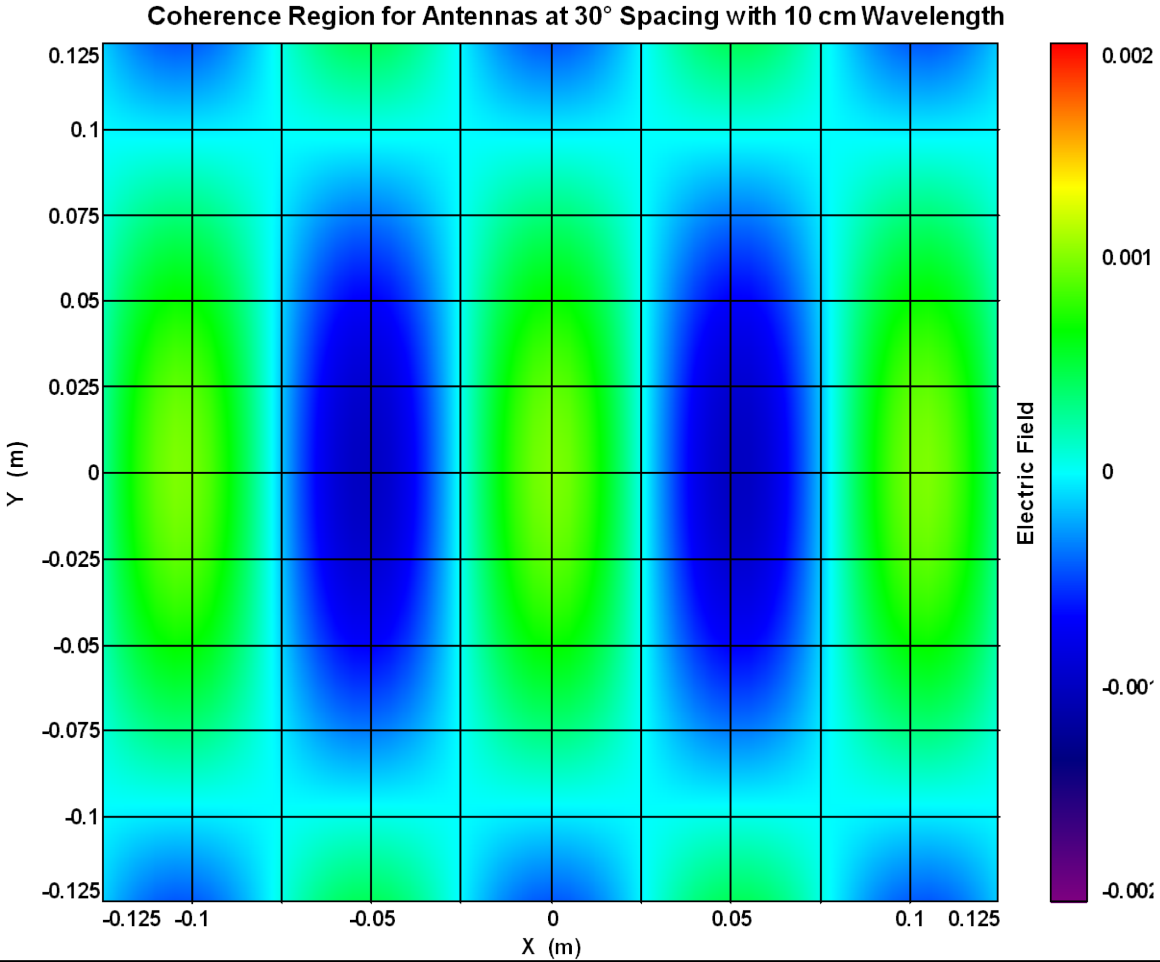

Designing an OTA Environment Simulator

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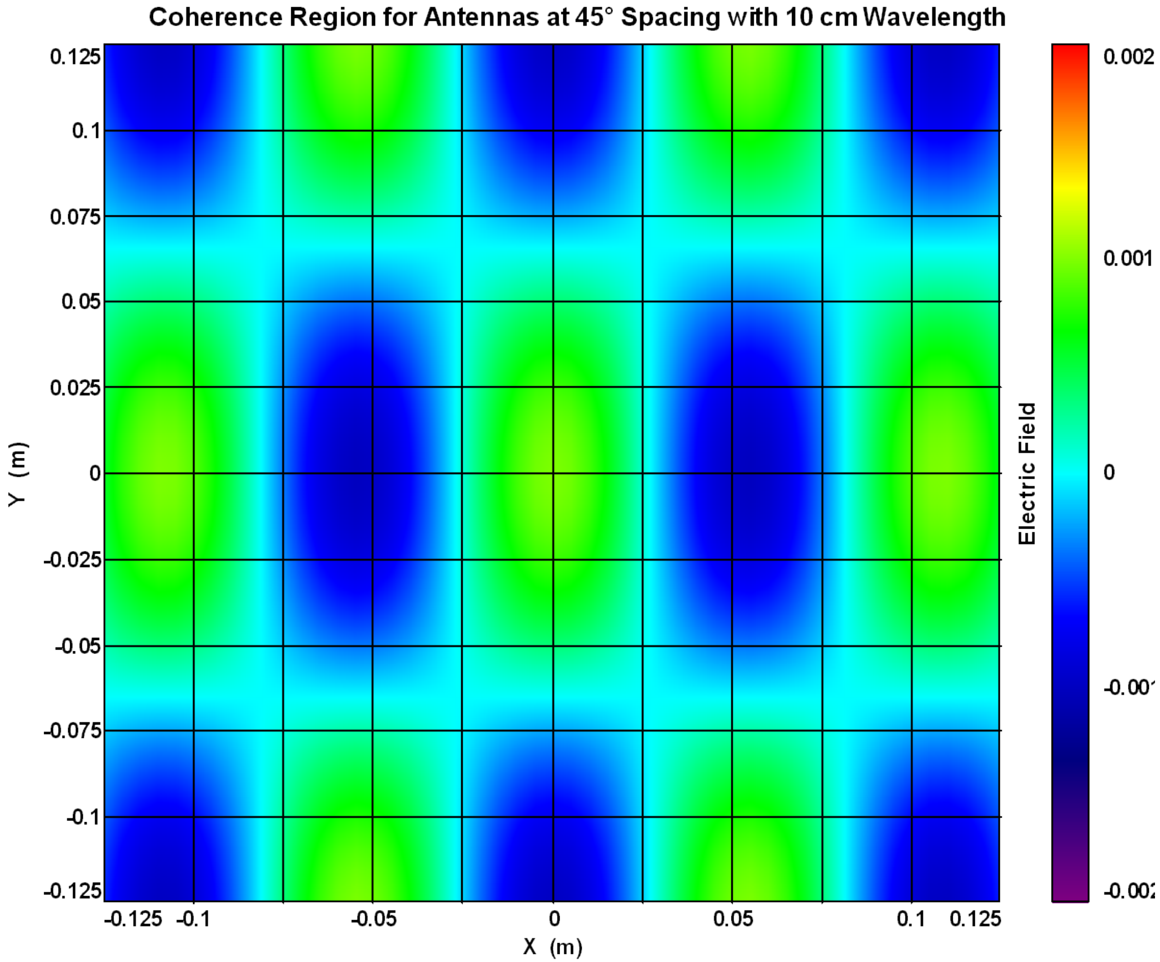

Designing an OTA Environment Simulator

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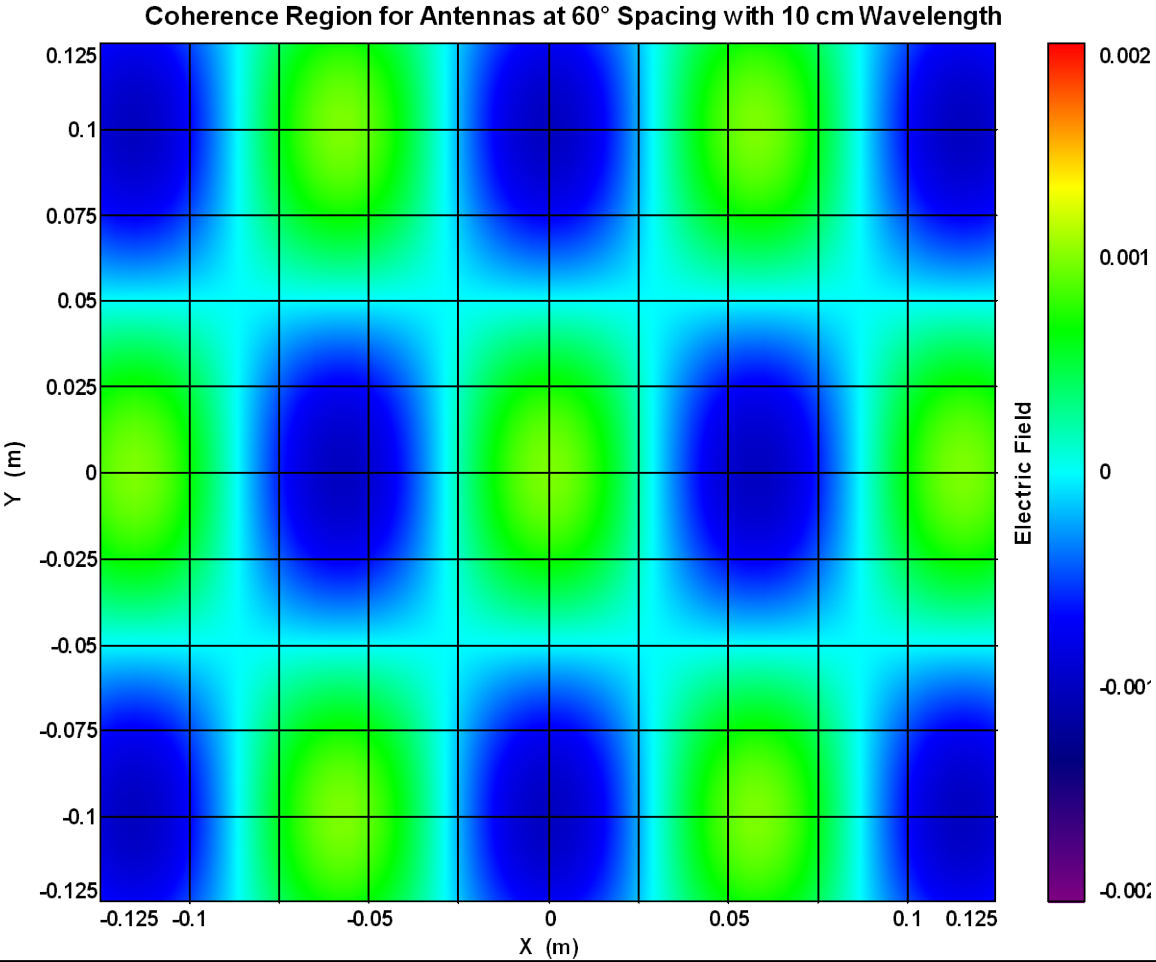
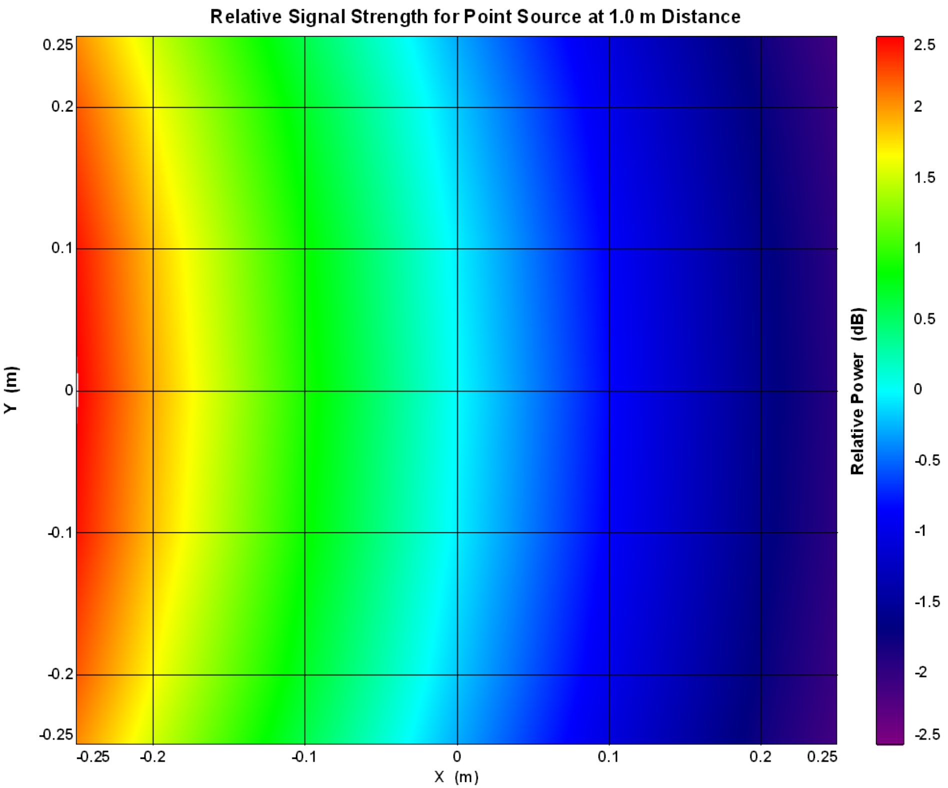
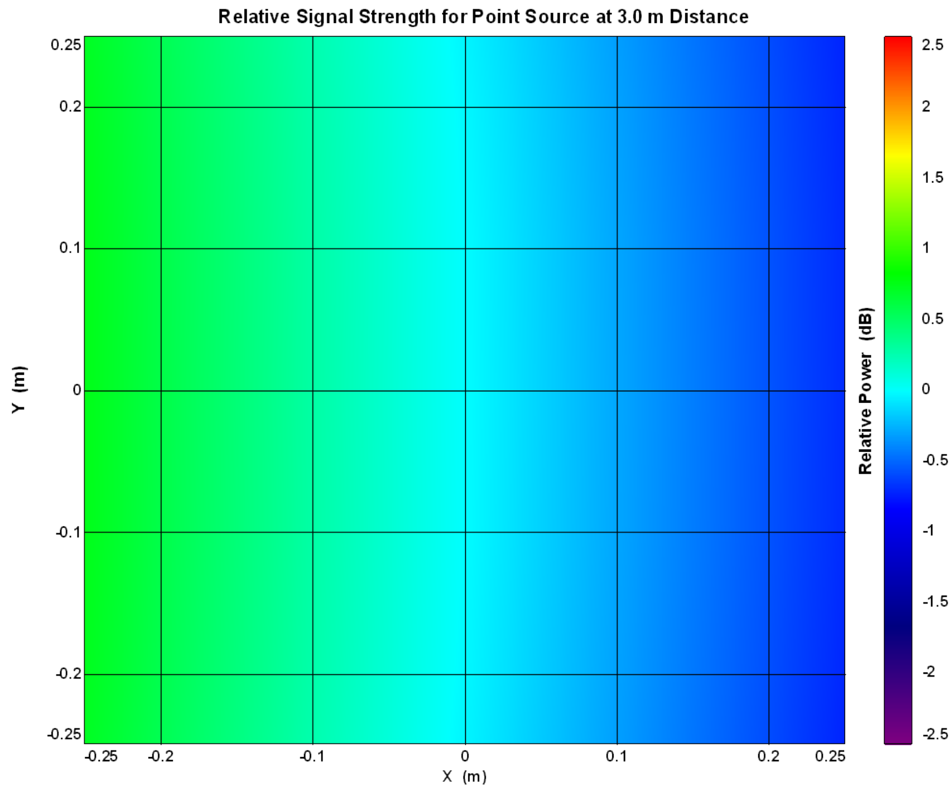


Designing an OTA Environment Simulator

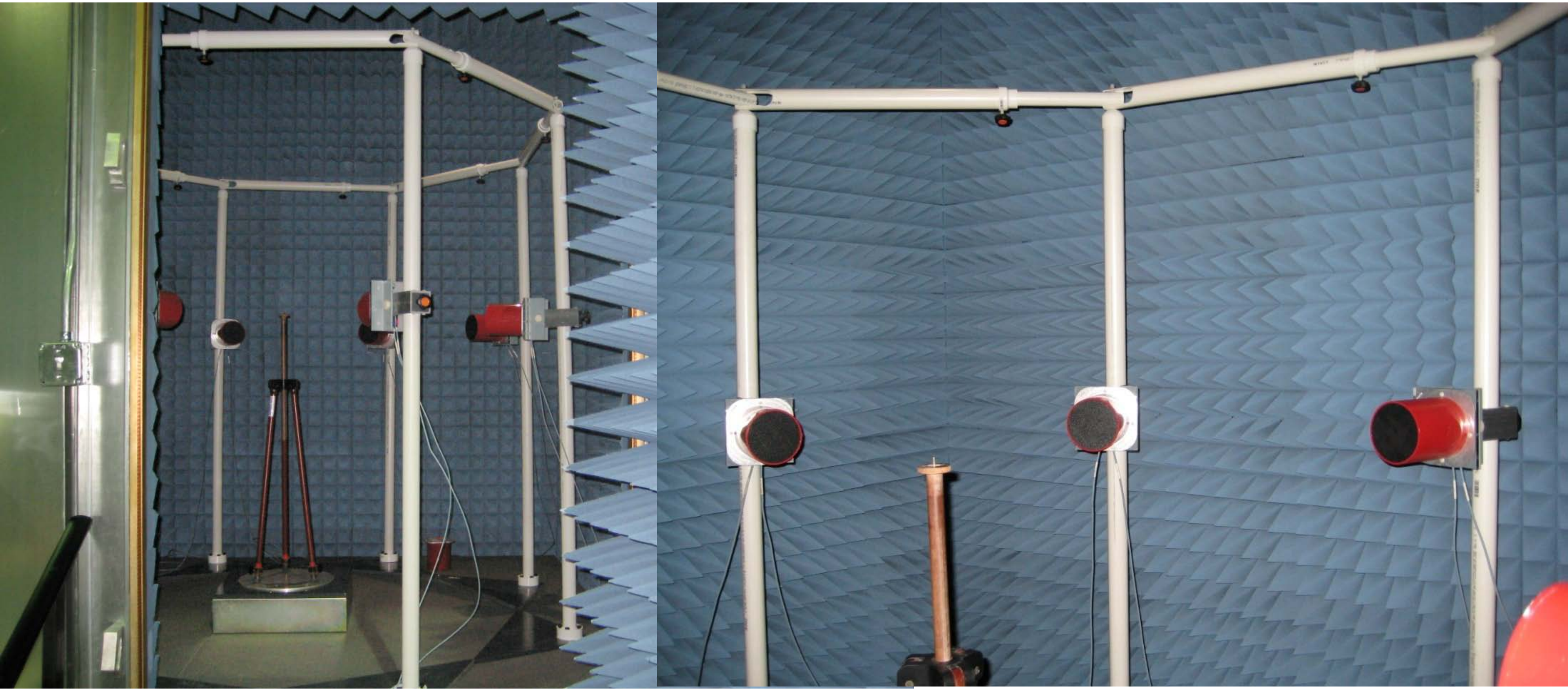
- **Radial fall-off from traditional antennas in close proximity to DUT does not behave like reflections from distant objects (i.e. non-plane-wave behavior).**





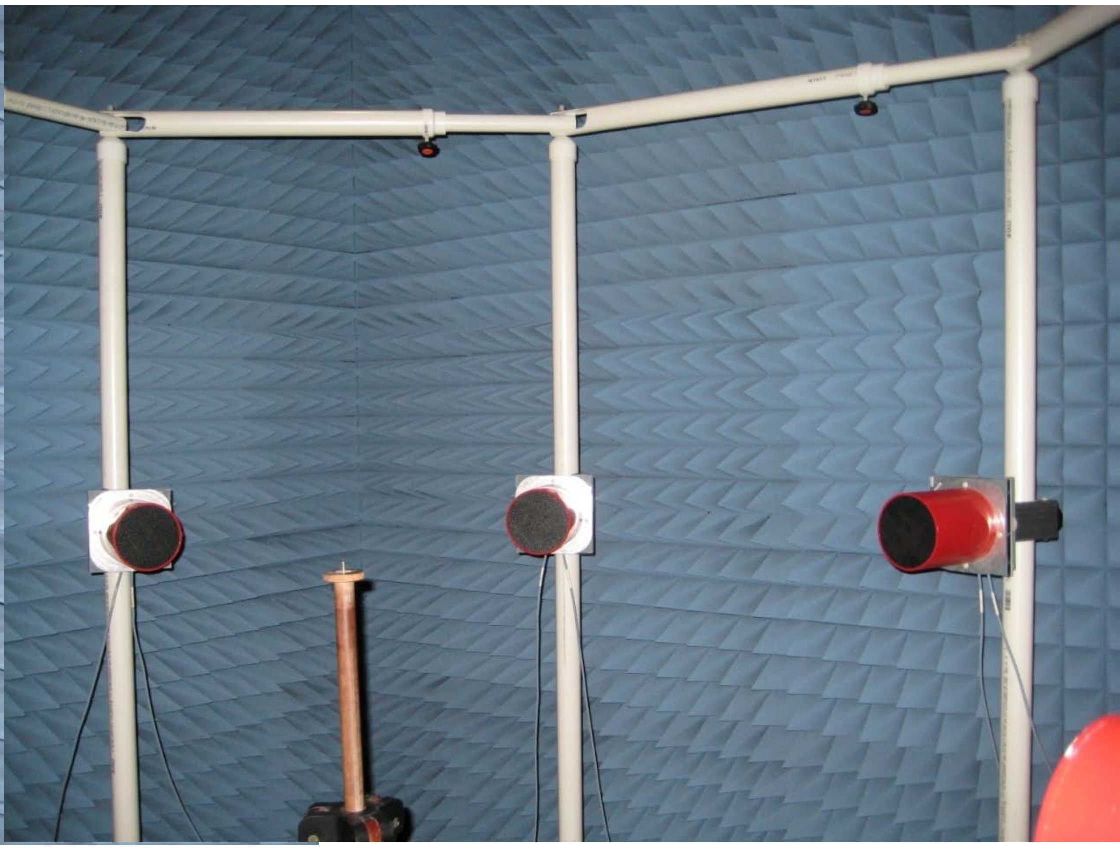
Initial R&D System Results

- **A re-configurable MIMO OTA system has been installed in ETS-Lindgren's Cedar Park facility for research and development of test requirements.**



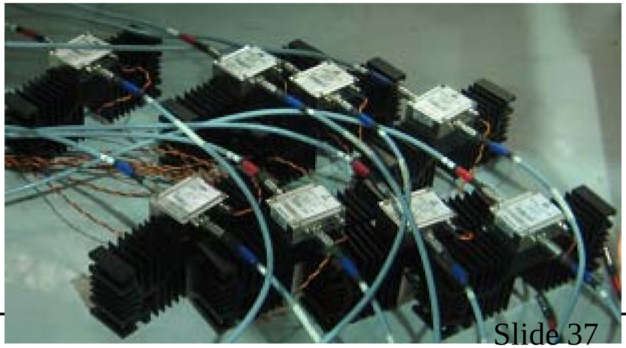
Initial R&D System Results

- **Eight dual polarized antenna elements are mounted on adjustable fixtures and arranged around a DUT positioning turntable.**



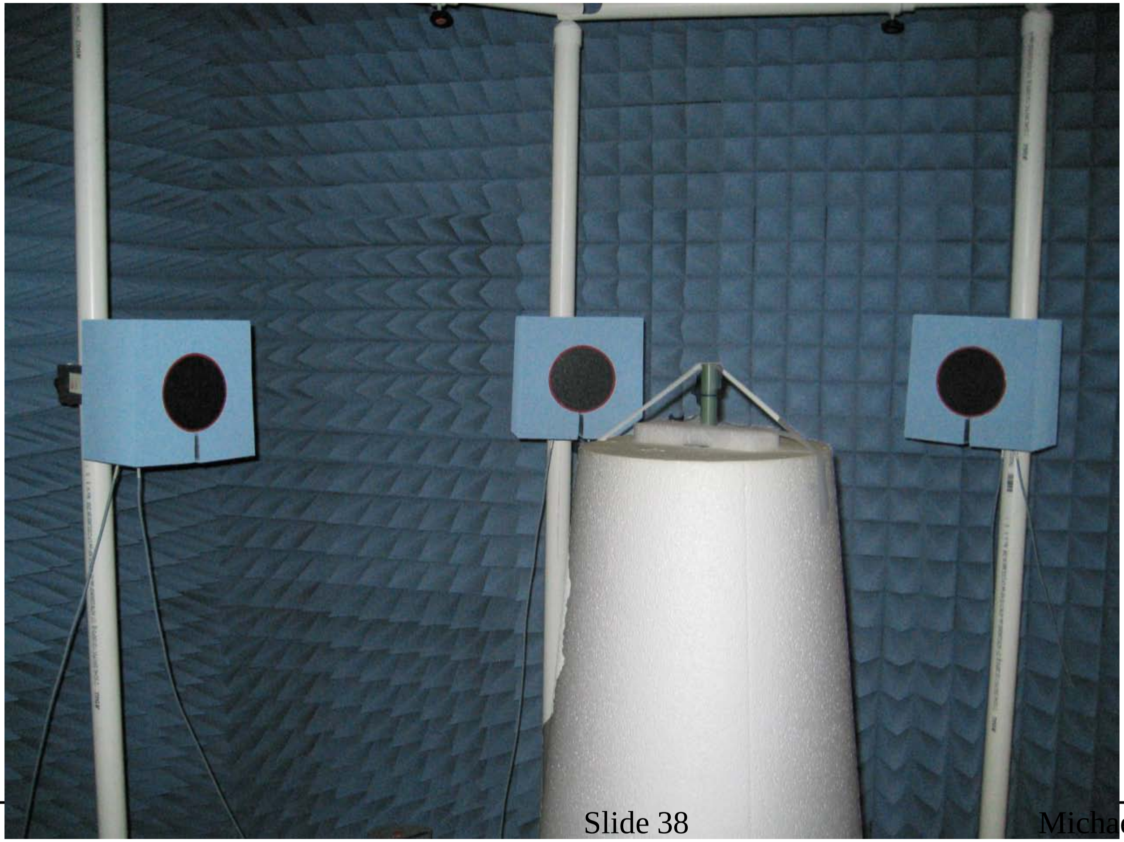
Initial R&D System Results

- **The Elektrobit Propsim F8 channel emulator was used to provide the spatial channel emulation required for the OTA environment simulation.**
- **Eight 30 dB gain power amplifiers drive eight vertical antenna elements.**



Initial R&D System Results

- **A 2.45 GHz Precision Sleeve Dipole was used to measure (calibrate) the vector path loss through the F8 and each antenna to the center of the test volume.**



Initial R&D System Results

- **An 802.11n 2x2 MIMO Wireless Router with removable, adjustable external antennas was chosen as the DUT.**
- **A matching NIC was used as the downlink source.**

- Directly cabled conducted tests were used to verify MIMO operation with appropriately higher throughput compared to SIMO/SISO cabled configurations.

Initial R&D System Results

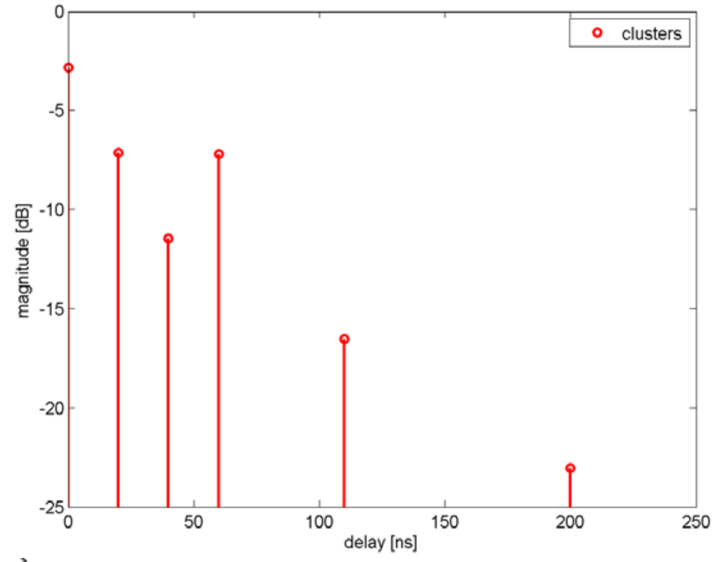
- **Conducted tests of throughput vs. attenuation were performed with Propsim F8 using circulators/isolators to provide a single return uplink.**
- **Direct single tap models were used to replicate cabled results for calibration.**

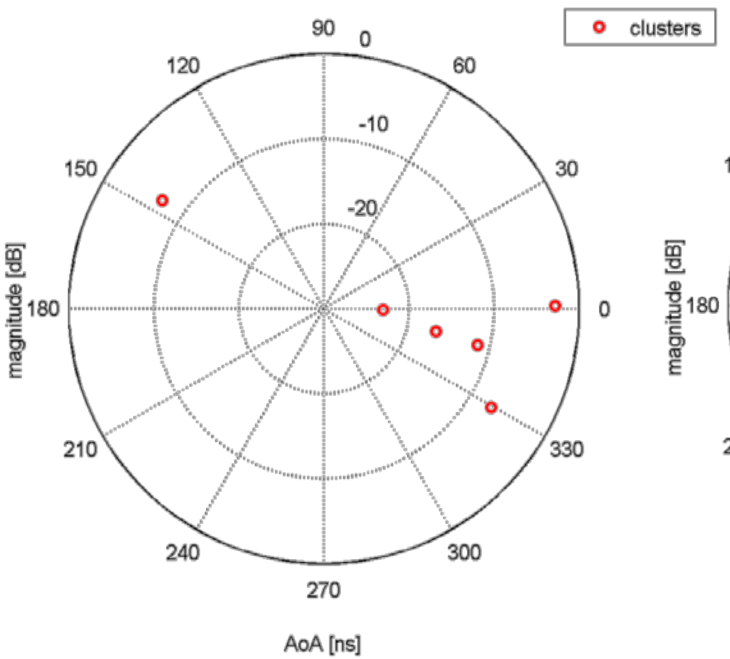
Initial R&D System Results

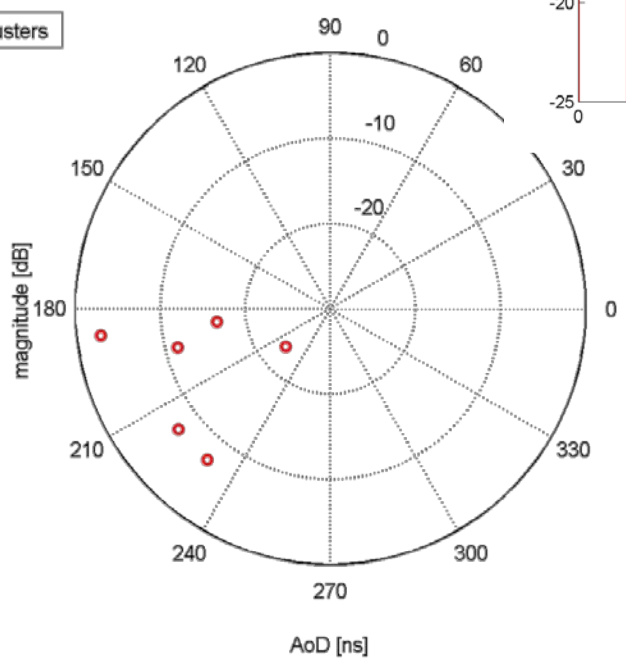
- **Several 2x2 MIMO models suitable for OTA testing were evaluated to determine typical MIMO performance.**
  - Modified SCME Urban Micro w/ 3 km/h fading & zero delay spread.
  - Modified TGn-C w/ AOD/AOA based on SCME
  - Modified TGn-C w/ low TX correlation (10 wavelength separation)

Initial R&D System Results

- **Modified TGn-C uses taps from TGn-C model with AOA/AOD from SCME Urban Micro model.**



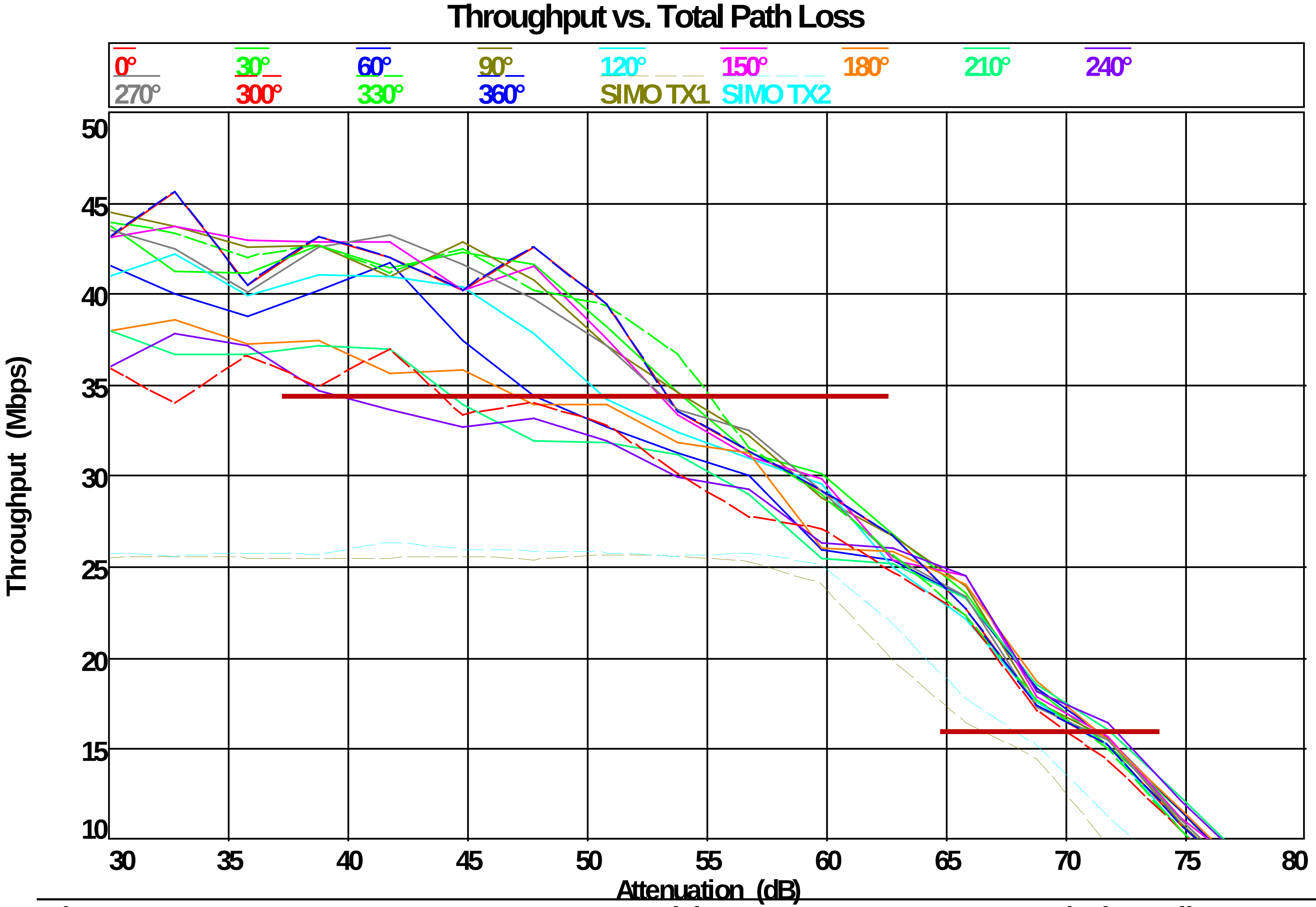




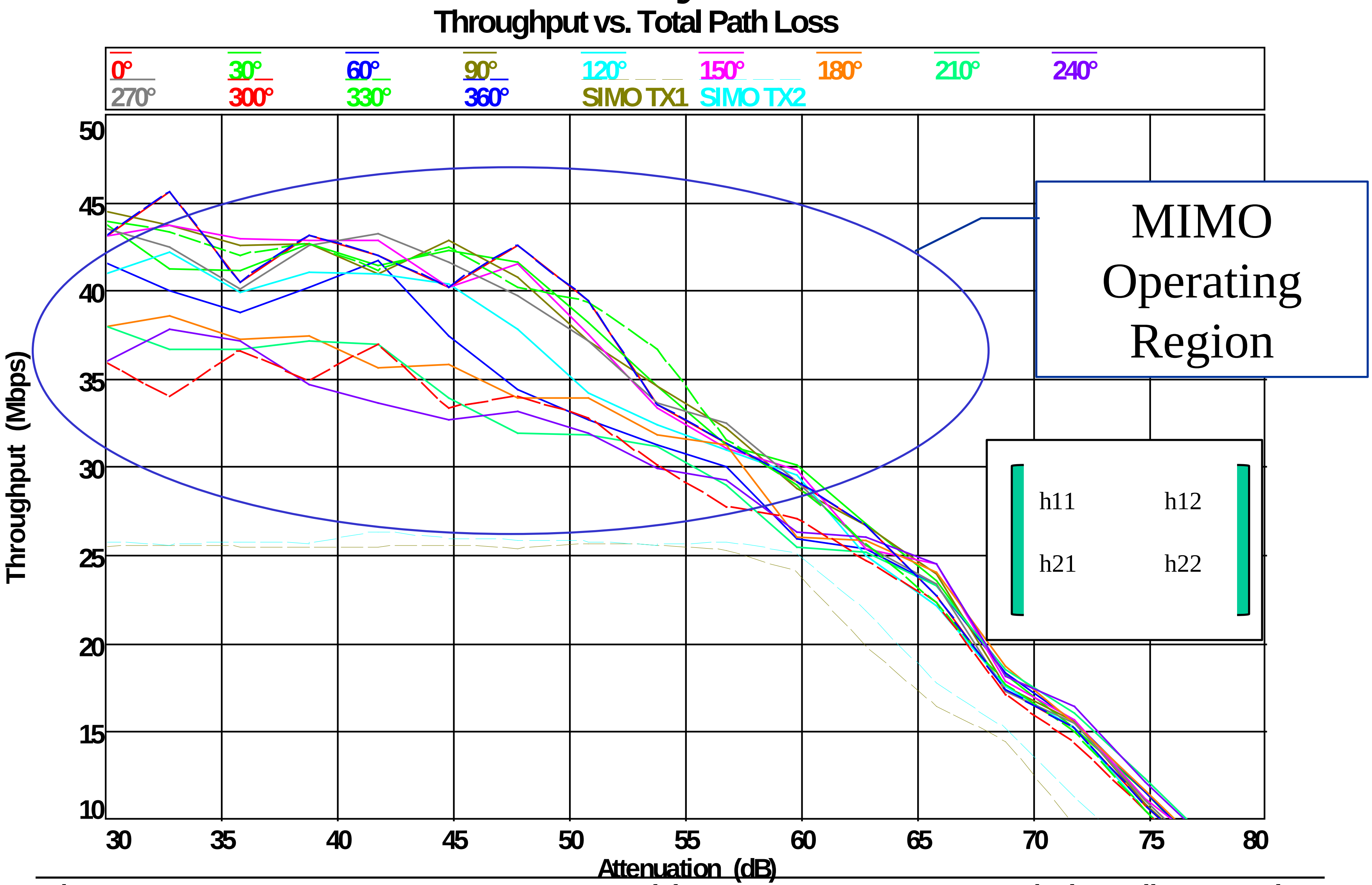
Initial R&D System Results

- Using standard 20 MHz 802.11 channels, conducted tests show maximum SIMO throughput around 25 MBPS, with MIMO performance around 40-45 MBPS with typical channel models.
- Initial OTA tests with stock antennas using low correlation TGn-C OTA model produces similar results but shows angular dependence of MIMO performance while SIMO (diversity) performance remains uniform.

Initial R&D System Results



Initial R&D System Results



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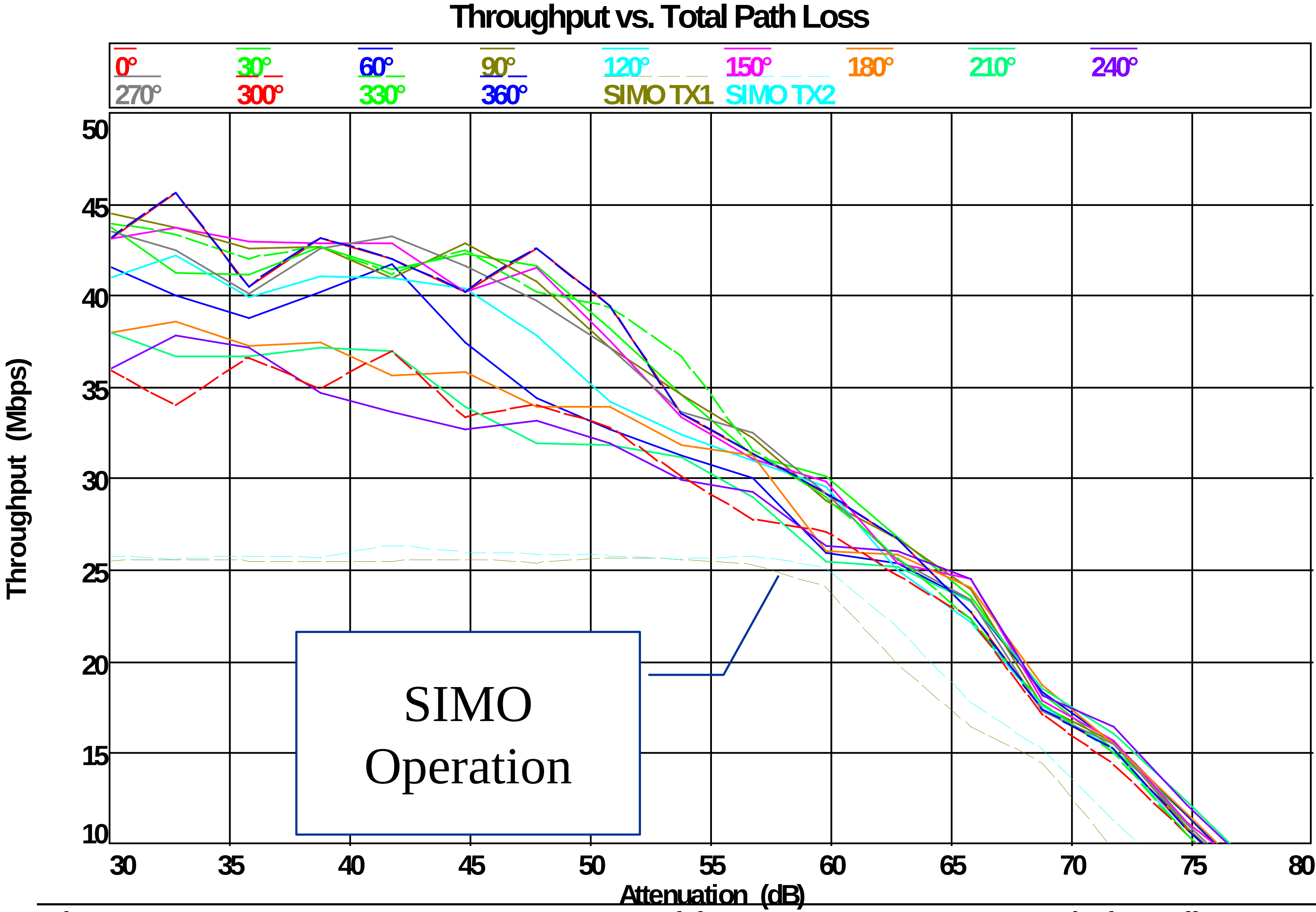

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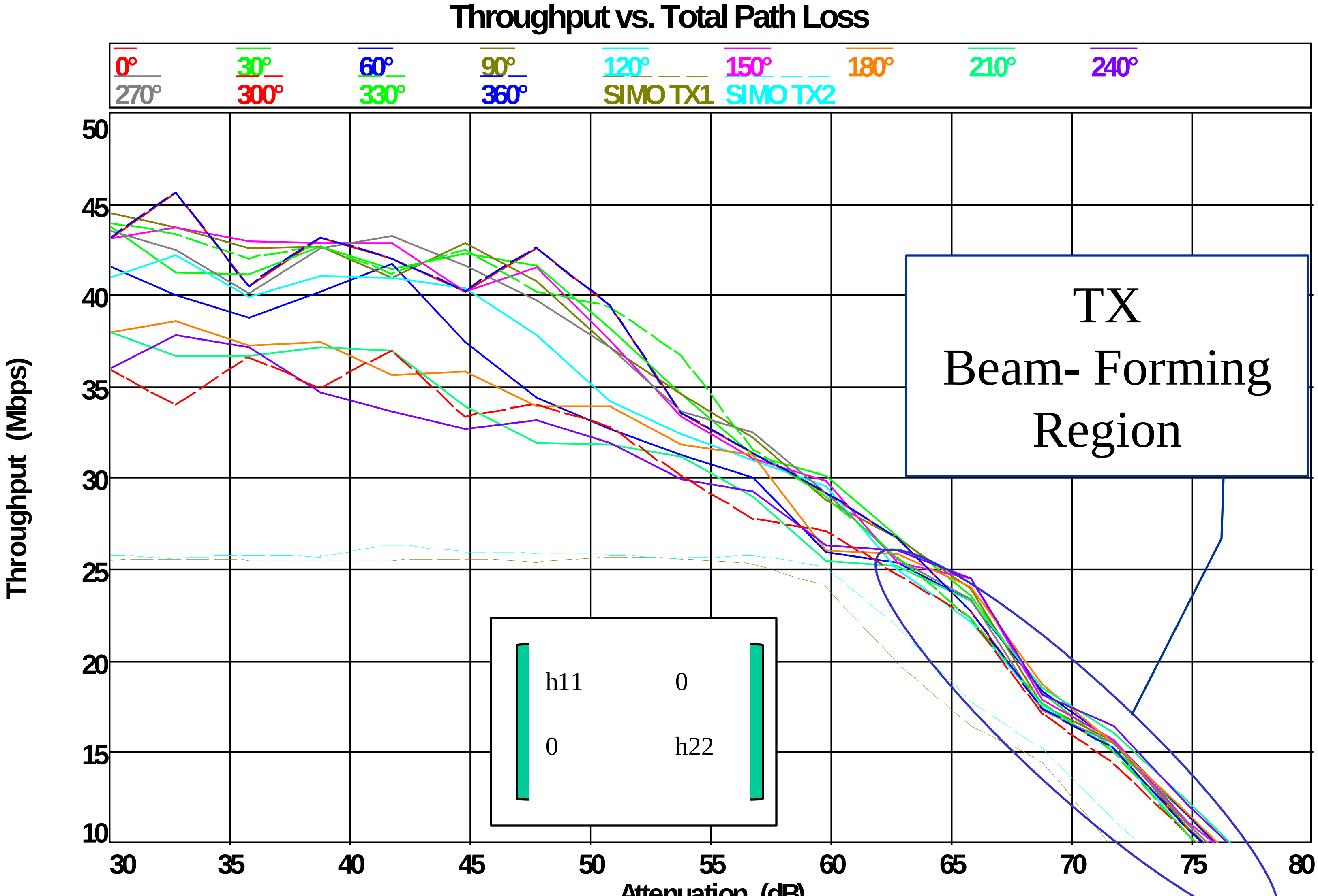

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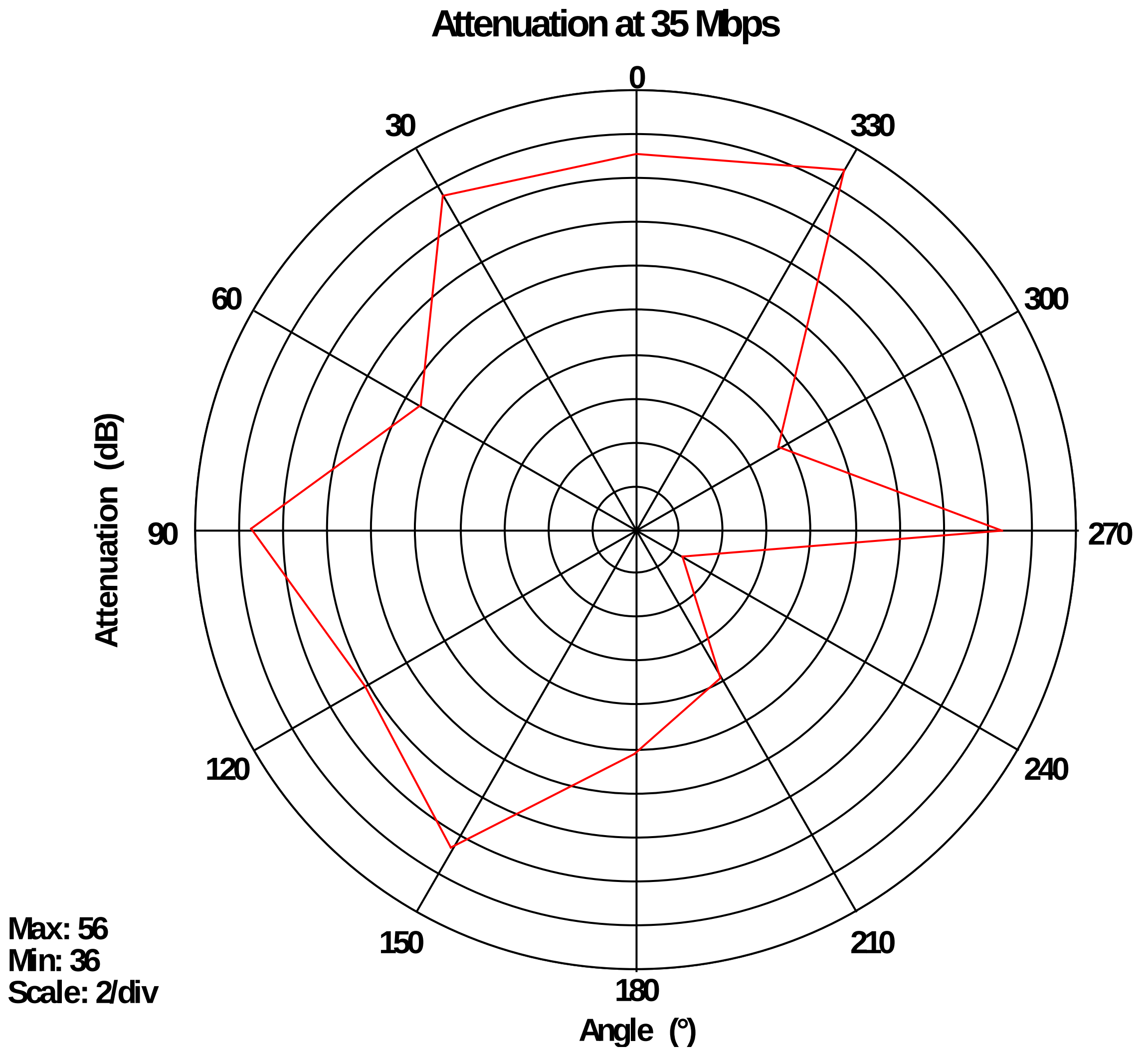

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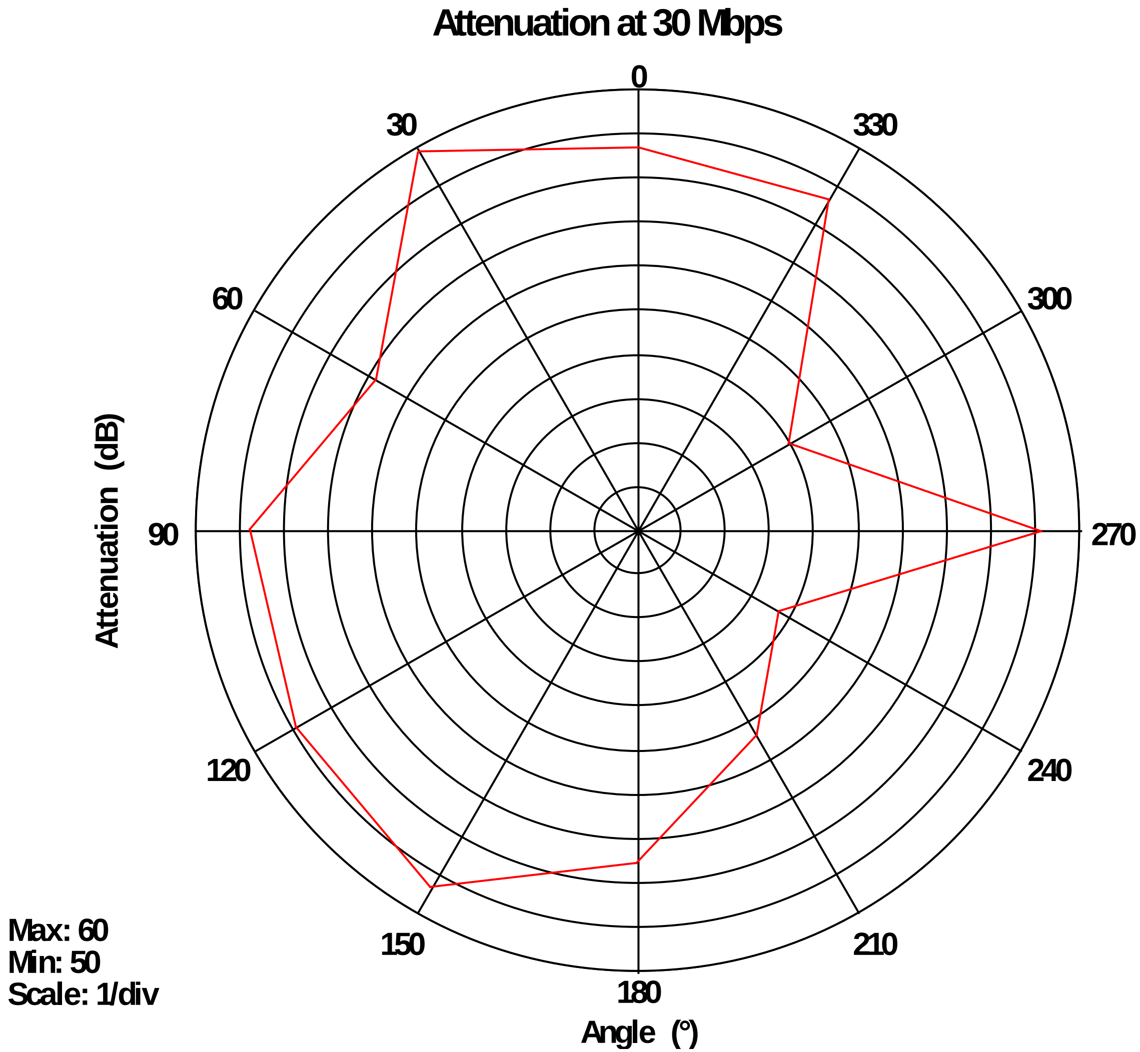

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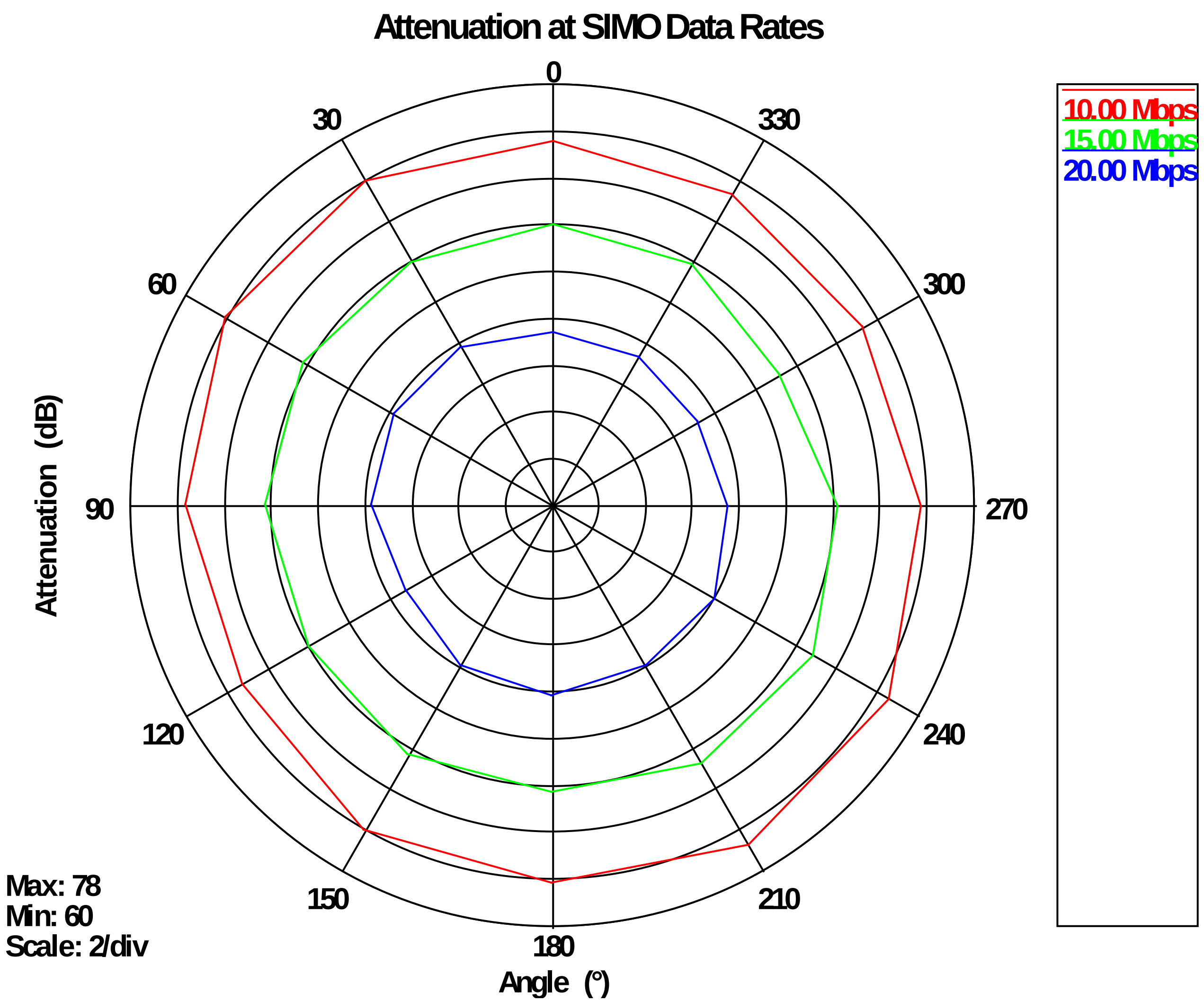
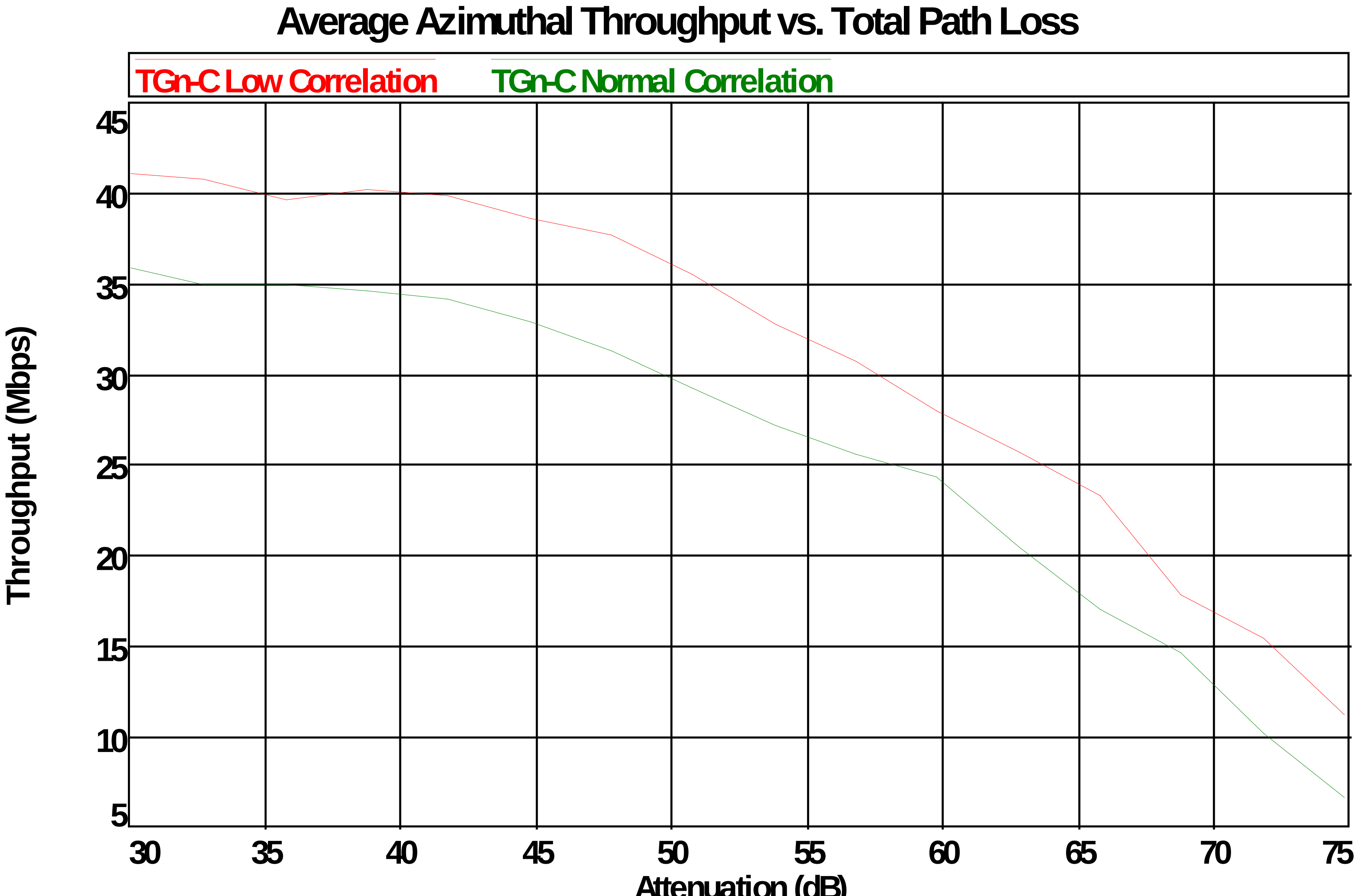


Metrics

- The data acquired thus far can be evaluated in a number of ways to define different metrics for MIMO performance.
- Removing the position axis produces average throughput vs. power (attenuation) curves.
- This could be done as a post processing step, but if position (pattern) information is not needed, average throughput performance can be determined by moving DUT continuously through simulated environment.

Metrics



Average Azimuthal Throughput vs. Total Path Loss
TGn-C Low Correlation
TGn-C Normal Correlation
Throughput (Mbps)
45
40
35
30
25
20
15
10
5
30
35
40
45
50
55
60
65
70
75
Attenuation (dB)

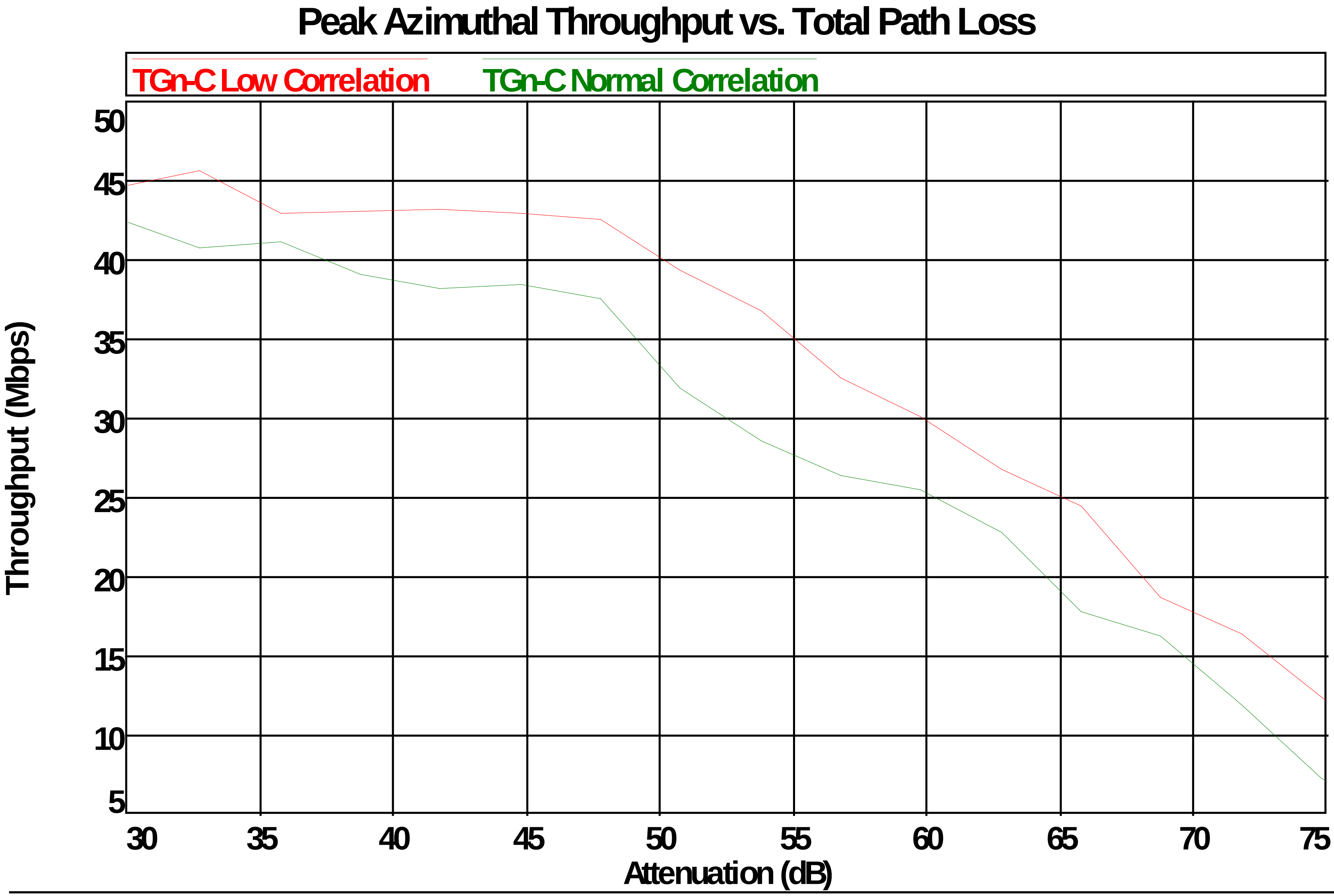
Metrics

- **This test can be further reduced by choosing to determine average throughput performance at a given field level (no power level search).**
  - E.g. At an attenuation value of 50 dB, this DUT has an average throughput of 36 Mbps for the low correlation TGn-C model and 30 Mbps for the normal correlation TGn-C model.
- **This is similar to many conformance tests with a simple pass/fail result, and assumes a minimum expected network capability.**

Metrics

- **By retaining angular information, or by measuring throughput over short dwell times as the DUT moves, peak throughput performance can be determined.**
- **This metric may have limited usefulness, but does illustrate a slightly different reaction to the two models.**

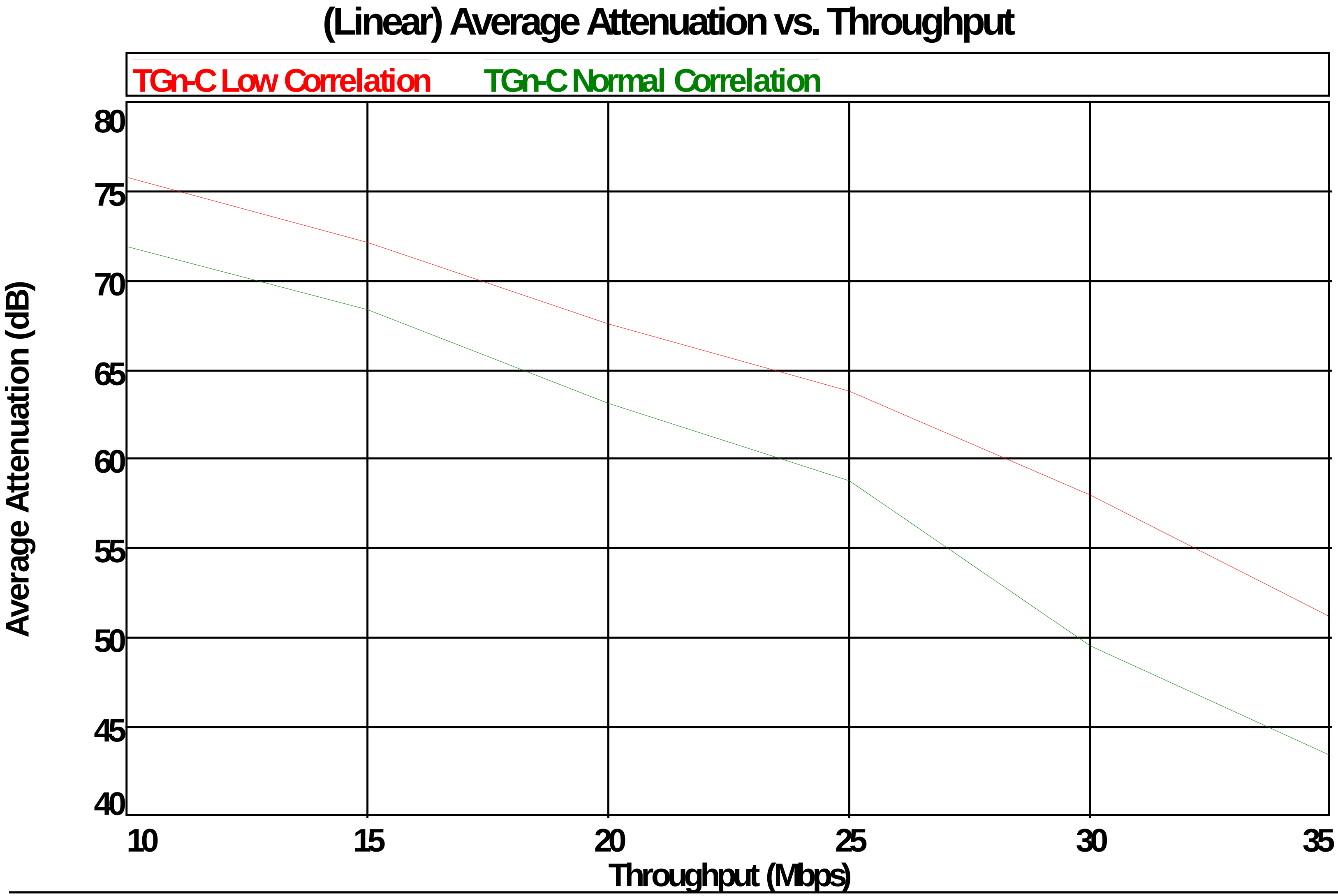
Metrics


Peak Azimuthal Throughput vs. Total Path Loss
TGn-C Low Correlation
TGn-C Normal Correlation
Throughput (Mbps)
50
45
40
35
30
25
20
15
10
5
30
35
40
45
50
55
60
65
70
75
Attenuation (dB)

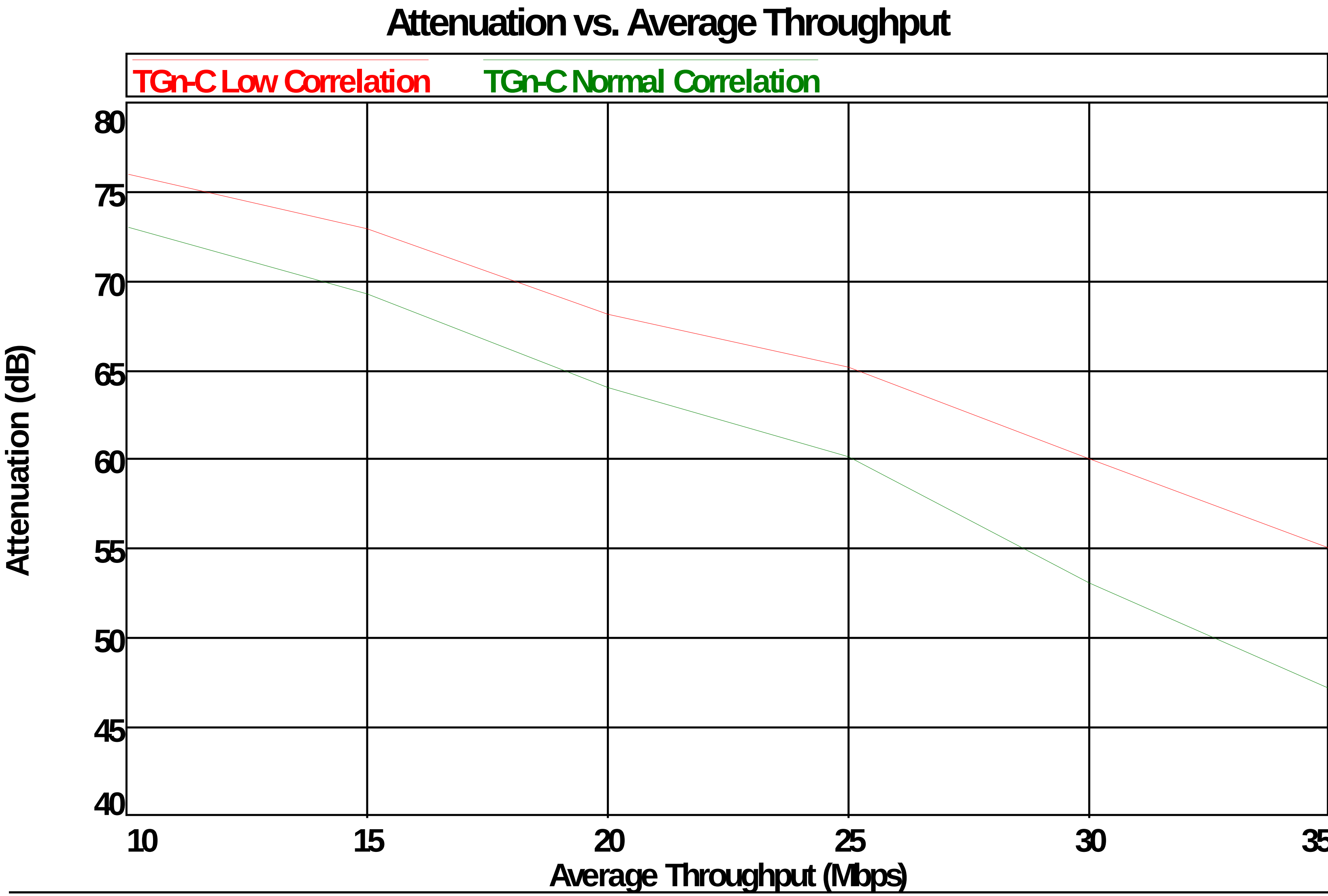
Metrics

- **By retaining throughput vs. attenuation or using a throughput vs. attenuation search mode, one can define a "MIMO Sensitivity" where throughput falls below a certain target.**
- **This can be defined in two ways, with varying test time requirements.**
  – Average power required to produce the target throughput at each angle (integrated TIS pattern)
  – Power required to produce desired average throughput as device is rotated through all angles

Metrics


(Linear) Average Attenuation vs. Throughput
TGn-C Low Correlation
TGn-C Normal Correlation
80
75
70
65
60
55
50
45
40
Average Attenuation (dB)
10
15
20
25
30
35
Throughput (Mbps)

Metrics


Attenuation vs. Average Throughput
TGn-C Low Correlation
TGn-C Normal Correlation
80
75
70
65
60
55
50
45
40
Attenuation (dB)
10
15
20
25
30
35
Average Throughput (Mbps)

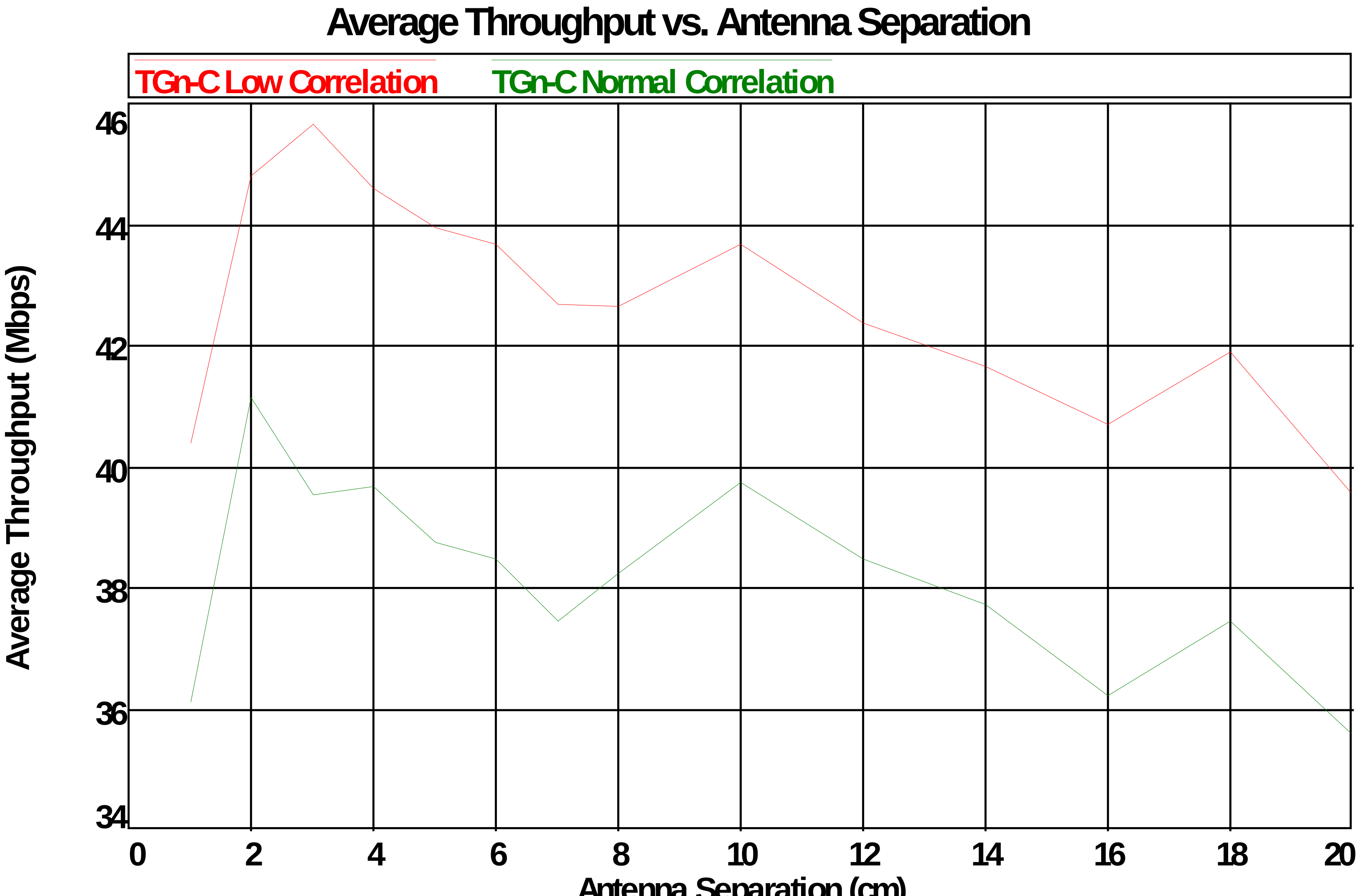
Metrics

- While the statistics of these two metrics are slightly different and provide slightly different results, both provide considerably more information on the DUT, offering an “edge of MIMO link” performance indicator.
- Such information can be used to rank products and influence improvements, while the previous pass/fail options only offer basic acceptability criteria.

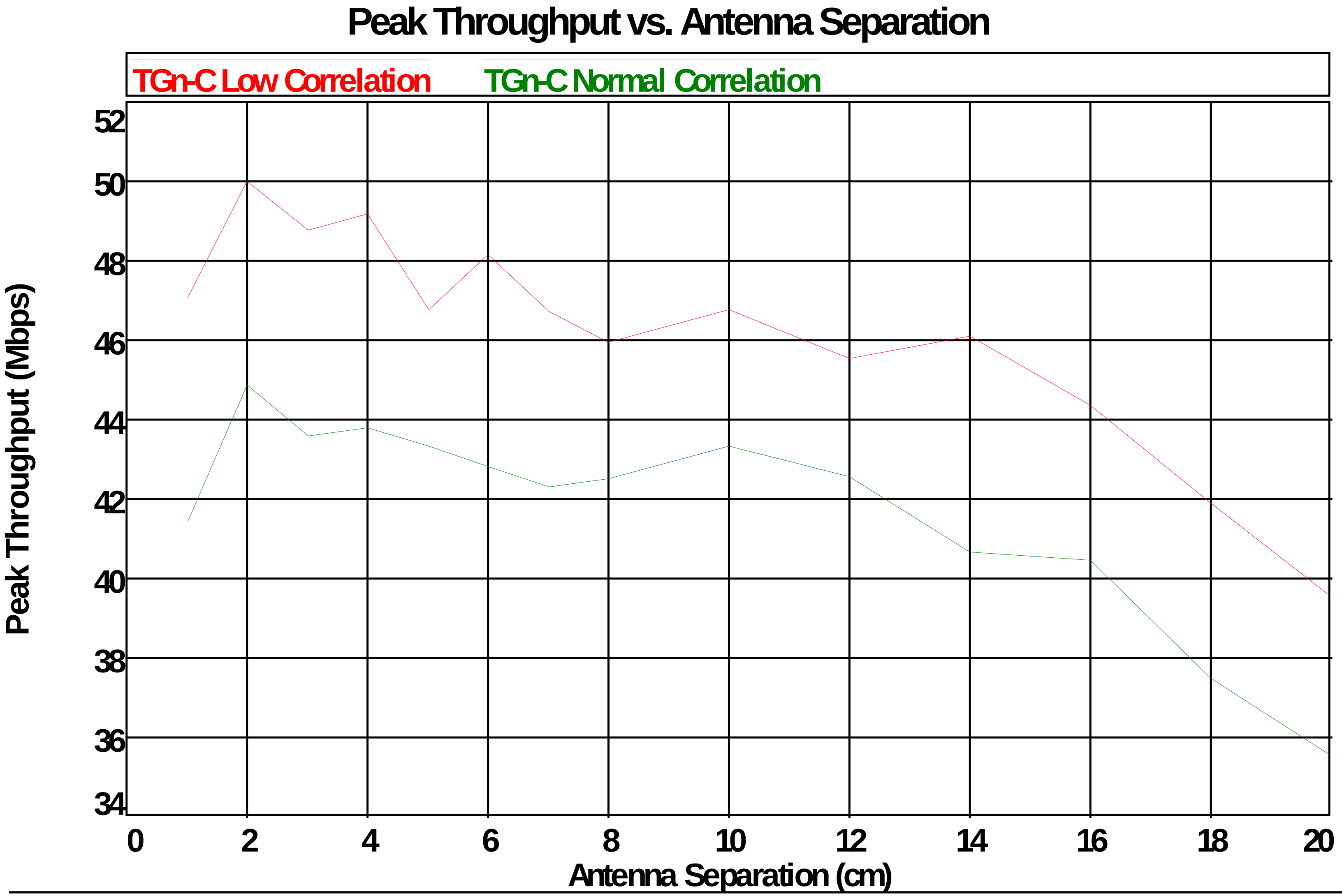
Correlation Evaluation

- **The eight antenna system was used to measure the effect of antenna separation on the throughput.**
- **In an ideal environment, throughput would increase as the antennas separate (reducing correlation) until some maximum is reached.**
- **In the imperfectly simulated environment, correlation "repeats" limiting the effectiveness of this evaluation for a given angular resolution of the measurement antenna array.**

Correlation Evaluation



Correlation Evaluation



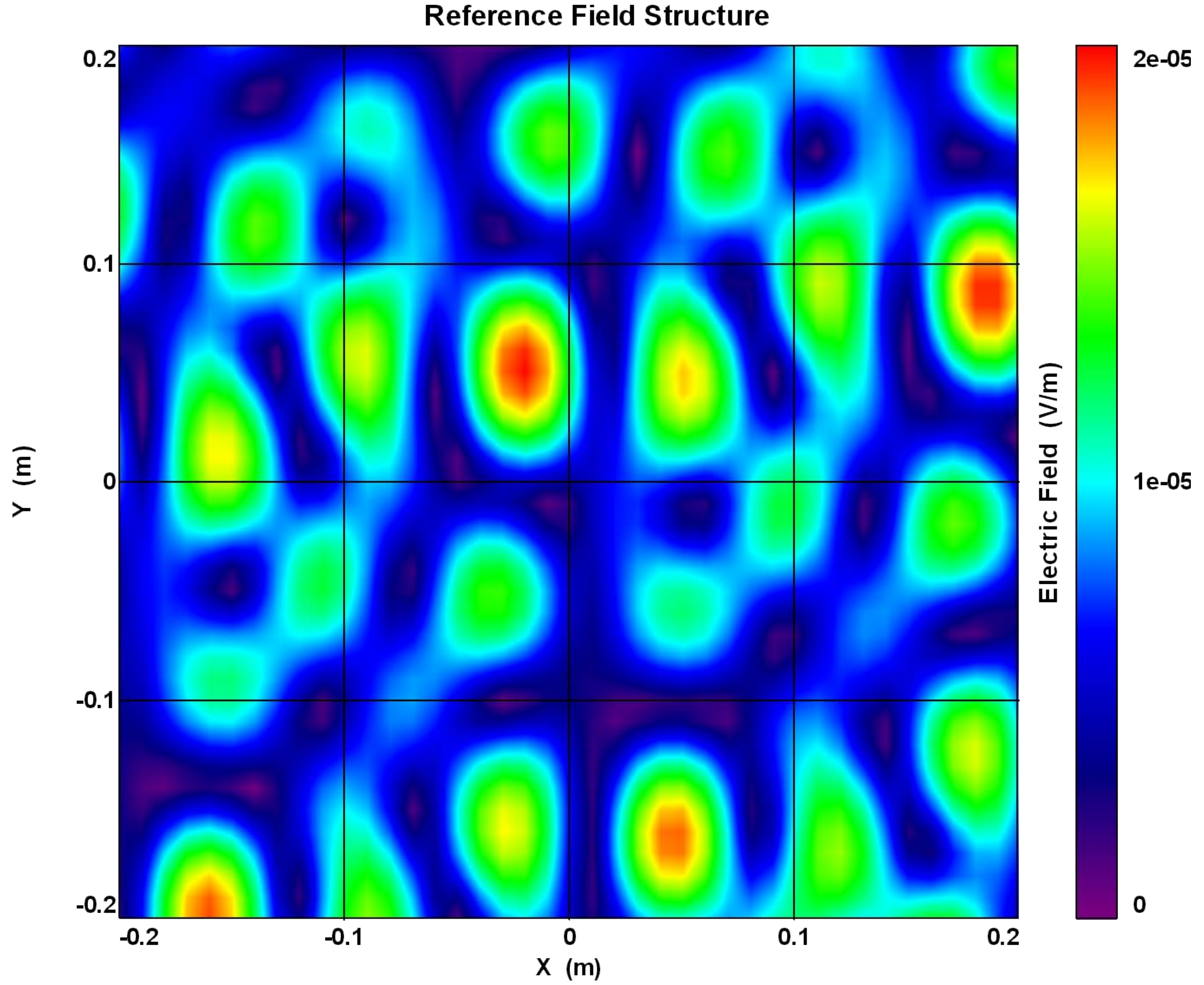
Correlation Evaluation

- **At 2.412 GHz the wavelength is ~12.4 cm.**
- **Normally the throughput would be expected to peak as the separation approached a wavelength or more.**
- **However, with antennas at 45° spacing, the field pattern (correlation) starts to repeat after approximately one wavelength.**
- **Thus, the peak should be expected to be somewhere below one wavelength.**

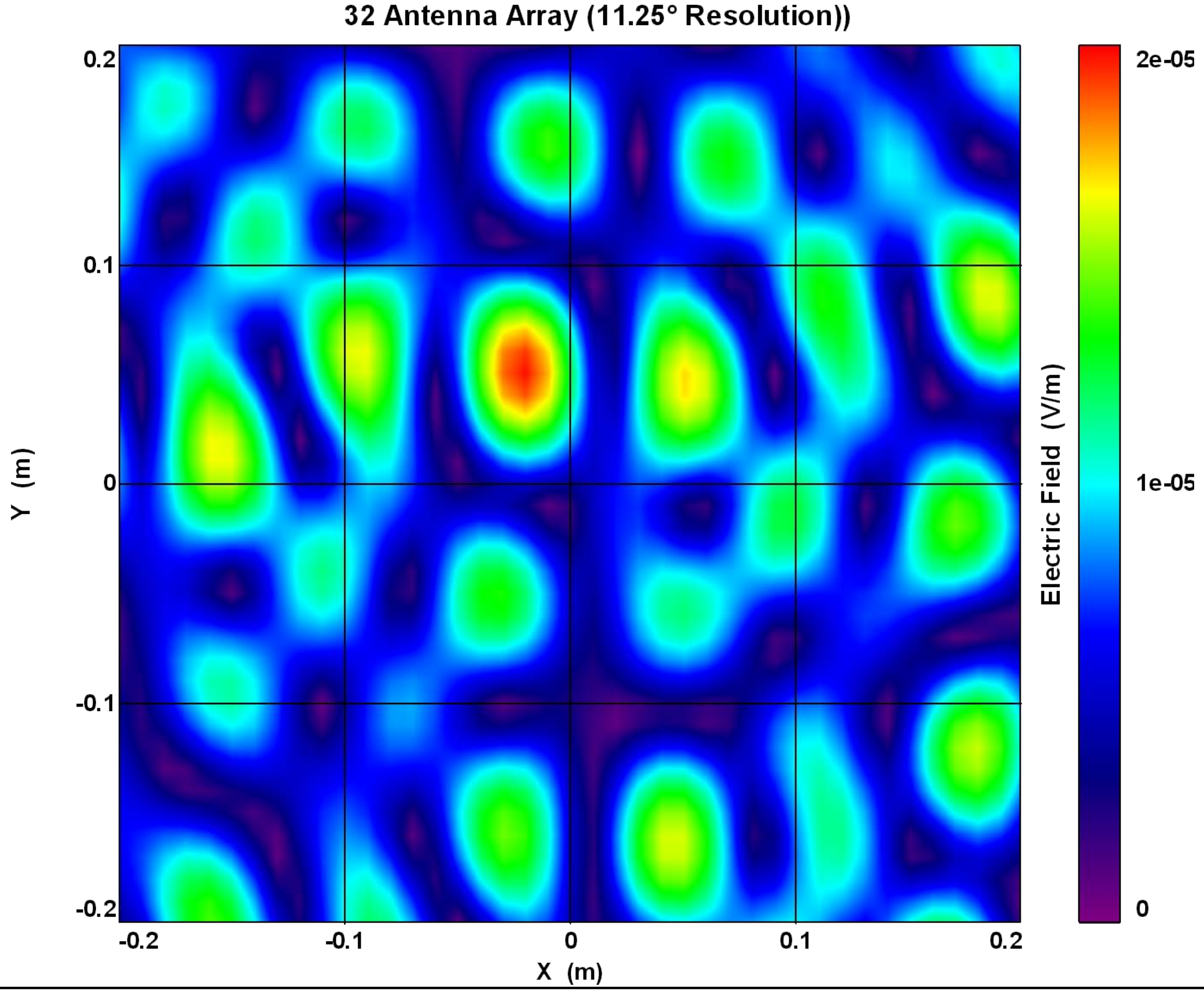
Correlation Evaluation

- **While there does appear to be a localized peak around 10 cm, the peak throughput is achieved around 2-3 cm (1/4-1/5 wavelength).**
- **This seems counterintuitive to our first assumptions about the correlation behavior of the simulated environment.**
- **An evaluation of the field structure is in order.**
- **The following slides illustrate a simple modeled field structure simulated by dipoles of varying angular resolution at 2 m distance.**

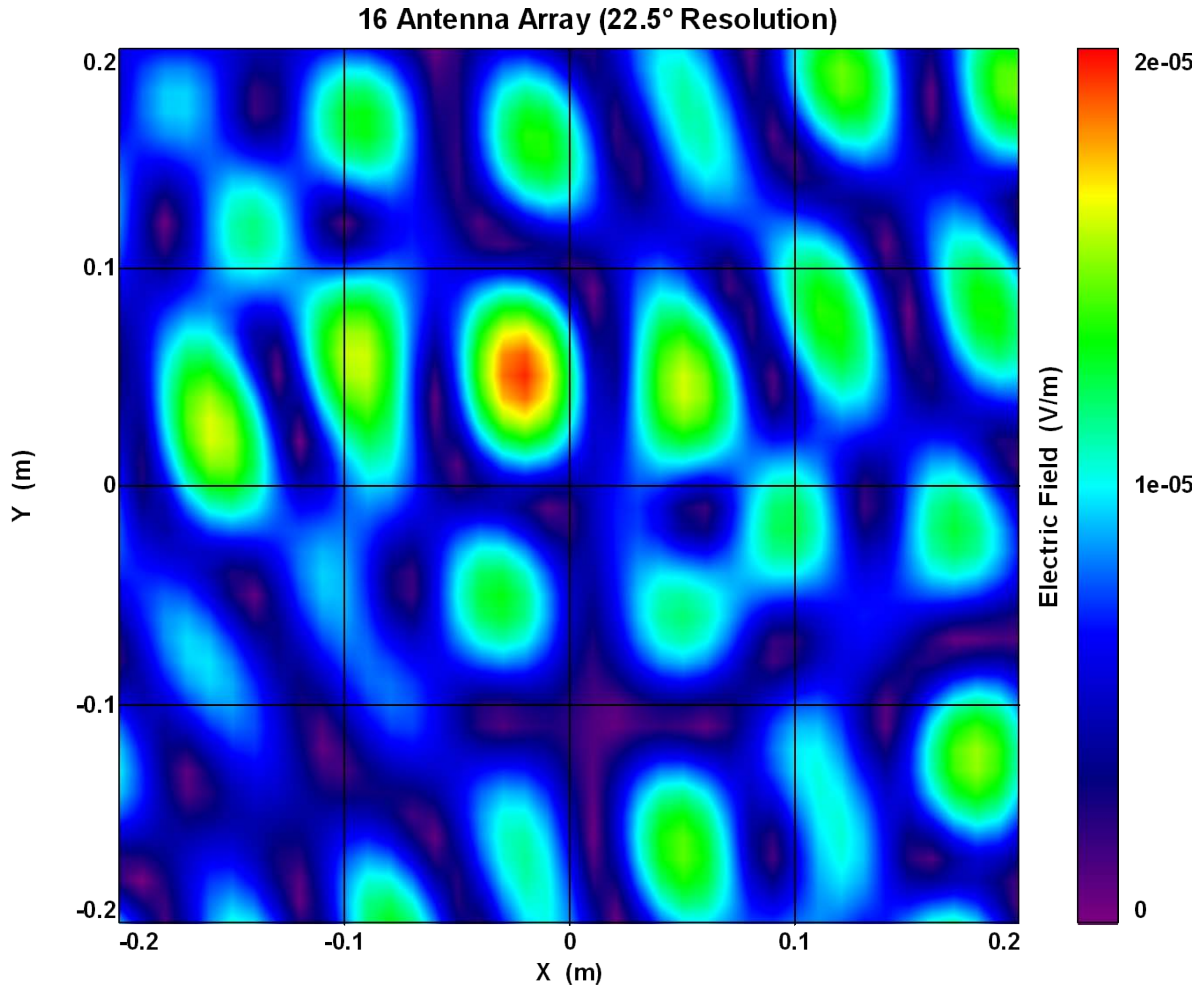
Correlation Evaluation



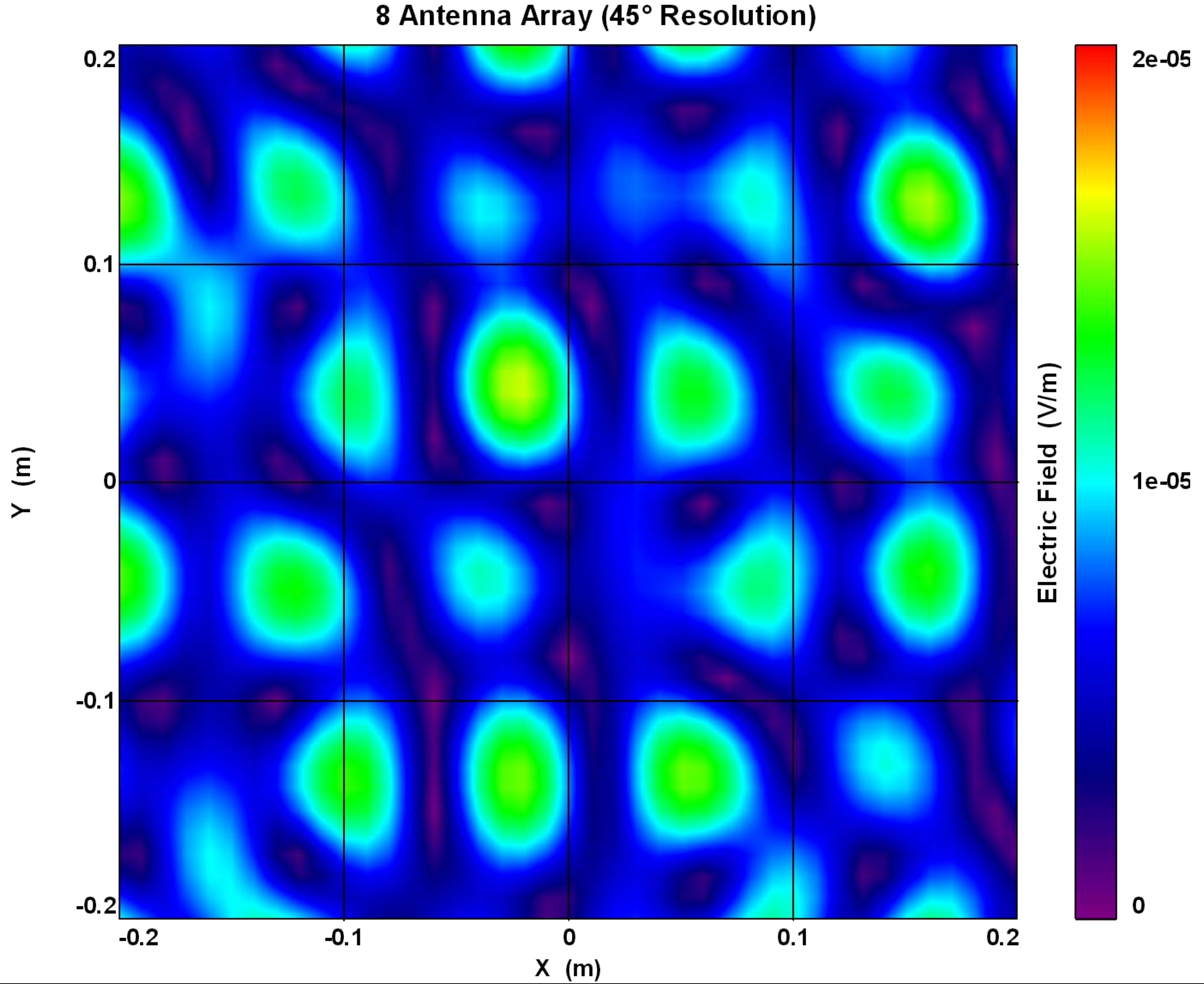
Correlation Evaluation



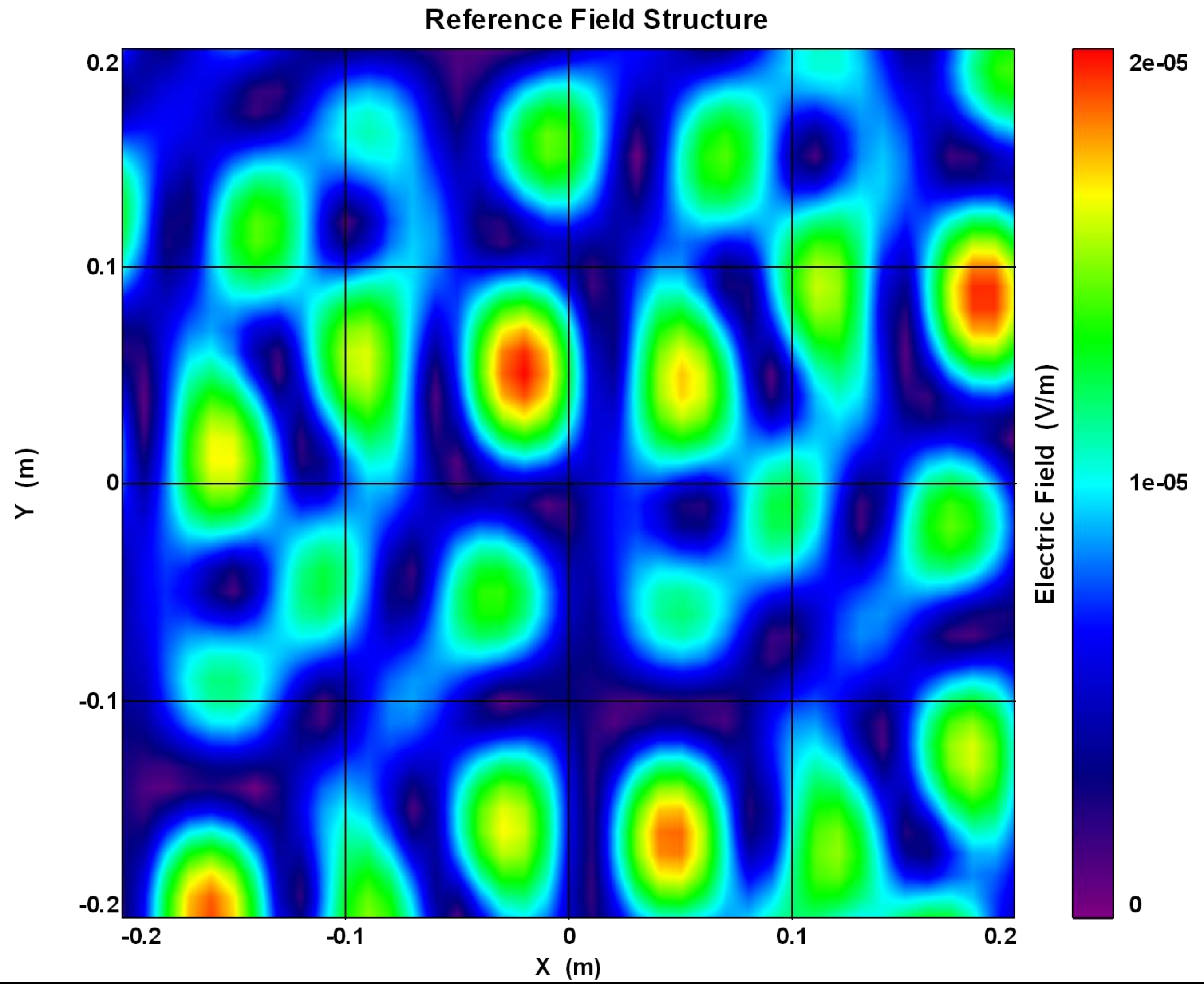
Correlation Evaluation



Correlation Evaluation



Correlation Evaluation



Correlation Evaluation

- **It’s apparent that at 45° spacing there is insufficient resolution to replicate even the most basic field structure.**
- **The nulls introduced by the interference pattern of the array prevent the field structure from reaching the desired magnitudes.**
- **Need finer resolution for design work, but may still be suitable for certification.**
- **Alternative is to choose simple target models to minimize range of required angles.**

Open Questions

- **How many OTA channel models should be simulated?**
- **What is the minimum number of antennas required to create the desired channel models.**
  - Are spherical arrays required or is a planar array sufficient?
- **How much statistical averaging is required for accurate estimation of device performance?**
  - For a given channel model, the device orientation should be varied to get an average performance.

Open Questions

- **What type of positioning of the DUT is required to obtain the desired statistical average?**
- **What metrics do we want to test?**
  - (Average) Throughput
  - Spherically averaged throughput (TRP/TIS analogue)
  - MIMO Sensitivity (edge of MIMO operation)
  - Beam-forming, Diversity, and other edge of link features
  - TRP and TIS

Conclusions

- A method for environmental simulation within a fully anechoic chamber has been developed for testing MIMO and related multi-antenna technologies.
- Experiments show that MIMO performance can be evaluated in an anechoic chamber.
- Sample metrics have been shown, but standardization is needed to choose most useful metrics.
- This methodology is being investigated for expected adoption by CTIA and 3GPP for LTE.